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Morphology and development of hatchery cultured American shad (Alosa sapidissima Wilson), with a comparison between field sampled and cultured

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MORPHOLOGY AND DEVELOPMENT OF HATCHERY CULTURED AMERICAN SHAD (*ALOSA SAPIDISSIMA* WILSON), WITH A COMPARISON BETWEEN FIELD SAMPLED AND CULTURED SPECIMENS

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TABLE OF CONTENTS

TABLE OF CONTENTS CONTINUED

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LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES CONTINUED

ABSTRACT

Morphometrics and meristics of larval Alosa sapidissima were examined and are described for hatchery reared samples. A. sapidissima (Wilson) morphometrics and body proportion ratios change with ontogeny in the larval stages. Head and snout length, eye diameter, and body depth exhibited a curvilinear relationship with increasing standard length, while preanal and predorsal length showed a linear relationship with increasing standard length.

Predorsal and preanal myomere counts on A. sapidissima decreased during ontogeny with the corresponding anterior dorsal fin migration and shortening of the gut. Other meristics indicated that median fin development was completed between 17 to 21 mm SL, while paired fin development was completed between 23 to 28 mm SL. A developmental sequence of the various caudal fin components showed a distinction between preflexion, flexion, and postflexion larva. Staining techniques utilized indicated that the development of hyperals and notochord flexure were important in distinguishing the stages of development.

Pigmentation showed a greater number and density of melanophores on cultured versus field sampled specimens. Stellate melanophores were found to contract and migrate on cultured samples. A sequence of pigmentation changes with ontogeny was described for future comparisons with field sampled larvae.

Morphometric differences between wild and cultured samples of A. sapidissima were not found over a comparable range of SL (19 to 31 mm). Both univariate and multivariate analytical techniques indicated no significant differences between the two populations of postflexion (juvenile) A. sapidissima.

MORPHOLOGY AND DEVELOPMENT OF HATCHERY CULTURED AMERICAN SHAD, *ALOSA SAPIDISSIMA* (WILSON), WITH A COMPARISON BETWEEN FIELD SAMPLED AND CULTURED SPECIMENS

INTRODUCTION

The American shad, Alosa sapidissima (Wilson), is a commercially and recreationally important clupeoid found in western North Atlantic coastal waters from Newfoundland, Canada to the St. Johns River, Florida (Hildebrand 1963; Scott and Crossman 1973). Chittenden (1969), Leim (1924) and Watson (1968) have all reported on the commercial and recreational value of A. sapidissima. However, since 1900 A. sapidissima stocks have declined throughout their range. Many reasons have been cited for this decline in abundance; Watson (1968) speculates that dams, overfishing, pollution, and overall environmental change may be reasons for the decline, while studies by Marcy (1976) on the effects of larval fish entrainment in power plants indicate that this may be a factor in the overall decline of A. sapidissima stocks.

A. sapidissima is an anadromous species that spawns in tidal freshwater tributaries. Spawning appears to be temperature dependent (Carscadden and Leggett 1975; Leggett and Whitney 1972). This dependence is indicated by the protracted spawning season along the Atlantic coast (Chittenden 1975; Leim 1924; Massmann 1952; Watson 1968). A. sapidissima spawn in the St. Johns River, Florida, in late winter (Hildebrand 1963). In the Chesapeake Bay tributaries spawning occurs in March and April (Massmann 1952), and in the Connecticut river in May and June (Marcy 1976). After spawning, larvae remain in the freshwater tributaries until the first winter when as juveniles they migrate offshore (Chittenden 1969; Talbot and Sykes 1958).

Life history studies of A. sapidissima have primarily been limited to the juvenile and adult stages of development (Chittenden 1969, 1972, 1975, 1976; Carscadden and Leggett 1975; Leim 1924). Early life history studies of A. sapidissima have generally been limited to the eggs and field collected samples of larvae and juveniles (Chittenden 1972; Leim

1924; Marcy 1976; Watson 1968). Consequently, this has left a gap in the literature for an adequate description of the larvae from yolk absorption through the juvenile stage of development.

The sequence of egg development for A. sapidissima has been adequately described by Hildebrand (1963), Marcy (1976), and Watson (1968). The larvae between yolk absorption and the juvenile stage have been described inadequately. Leim (1924) described yolksac larvae and field sampled larvae up to 28 mm in length. Hildebrand (1963) described yolksac larvae and briefly described the larval development through the juvenile stage. Jones et al. (1978), Lippson and Moran (1974), and Mansueti and Hardy (1968) all summarized early development studies of A. sapidissima. The approach used for these larval studies appears to be a static technique, which describes a few larvae over a few selected or sampled size ranges.

The purpose of this paper is to describe the larval development of A. sapidissima from yolk absorption to the juvenile stage of development. Data on yolksac larvae were collected and are presented for comparative purposes and future reference in Appendix 5. Description of A. sapidissima larval development is presented using the dynamic description approach of Moser and Ahlstrom (1970). This technique traces development from sequentially sampled specimens. Special attention is given in this work to morphology, meristics, and pigmentation. Early caudal developmental osteology is examined from sequential samples and a sequence of ossification is described. A comparison between cultured and wild sampled specimens is also made using both univariate and multivariate analytical techniques to test for differences in population morphometrics.

METHODS AND MATERIALS

Fertilization and Culture

Spawning adult A. sapidissima were sampled on the Pamunkey river, Virginia, throughout the spawning season (Figure 1). Eggs were field-stripped and fertilized by the method previously employed by the Massachusetts Division of Marine Fisheries (P. Rule, personal communication[1]).

Fertilized eggs were transported by placing approximately 1,100 eggs in aerated plastic bag liners, in 4.25 l glass jars filled with river water at ambient temperature. These containers were then placed in coolers lined with shock absorbing styrofoam. Eggs were oxygenated from a cylinder of oxygen during transportation to the culture system.

Eggs were cultured in a flow-through system designed by Blair (1976) with modifications made by Alan Blair[2] and the author at Harrison Lake National Fish Hatchery, Charles City, Virginia (Figure 2). Apparatus used in the system included three to five 10 l culture jars. A constant flow rate was maintained into an open trough of running water. The trough contained specially designed baskets fitted with saran screen for holding the newly-hatched A. sapidissima.

Environmental control and monitoring of the system included the use of thermoprobes for constant temperature monitoring. Previous monitoring of water temperatures during test cultures made in 1977 showed that a mean temperature of 19° C can be maintained for development of eggs and

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2 Alan Blair, Hatchery Manager, Harrison Lake National Fish Hatchery, U.S. Fish and Wildlife Service, Charles City, Virginia.

larvae. Natural (i.e. unregulate) lighting and photoperiod were used. Water flow rate was controlled at a constant rate of 1.0-1.5 liters per minute. This rate of flow was found to keep the eggs rolling adequately in the culture cylinders and keep fungus contamination to a minimum. Freshwater was gravity-fed from Harrison Lake, Virginia into the fish hatchery, and filtered to eliminate suspended materials. Newly-hatched yolksac larvae were transferred from the holding baskets to flow-through raceway troughs for growth and development (Figure 3). Temperature was continuously monitored, and flow rate periodically monitored, in the growth and development trough.

Sampling and Description

Larvae were sampled daily for the first thirty days, then weekly until the end of a 100 day sampling period. Samples were preserved by the method recommended by Berry and Richards (1973) in 10% buffered formalin.

Two developmental series of larvae were used in this study. Specimens in the first series were used for morphometric data, pigment patterns and larval illustrations. Those in the second series were cleared and counterstained by the method used by Dingerkus and Uhler (1977), and used for meristic and caudal osteology studies. Some specimens in the first series were subsequently used for staining in the second series after measurements, pigment patterns and illustrations were completed. Field specimens of A. sapidissima were also examined by the counterstaining technique.

Terminology of larval stages follows that of Ahlstrom, Butler, and Sumida (1976). The larval period is separated into three stages associated with caudal development. They are defined as preflexion, flexion, and postflexion stages of development. The yolksac larval stage of development is treated separately in this study, and only morphometric data is presented (Appendix 5).

Field Sampling

Larval and juvenile A. sapidissima were sampled on the spawning grounds (Figure 1) and used for comparative analysis of hatchery versus wild specimens. Sampling was completed using a framed 1.52 x 1.52 m pushnet (Kriete and Loesch 1980) every three weeks throughout the time postflexion and juvenile A. sapidissima remained on the nursery grounds. Measurements comparable to those taken on hatchery reared specimens were taken from wild specimens.

Morphometrics

Morphometrics were taken using an ocular micrometer, calibrated to the nearest 0.1 mm, in a dissecting microscope and a dial caliper, calibrated to the nearest 0.1 mm. Measurements follow closely those used by Houde, Richards, and Saksena (1974) and are described as follows:

Total Length (TL): Tip of the snout to the end of the caudal finfold complex in yolksac and preflexion larvae, and to the end of the longest superior procurrent caudal ray in flexion and postflexion larvae.

Notochord - Standard Length (SL): Tip of the snout to tip of the notochord in yolksac, preflexion and early flexion larvae; tip of snout to base of hypural plate in flexion and late flexion larvae, and tip of snout to the point midway between the tenth superior procurrent caudal ray and the first inferior caudal ray in postflexion larvae and juveniles. Unless otherwise noted in the text, all references to lengths of larvae refer to standard lengths. The use of this criteria for standard length measurements is based on that criteria used by Richards, Miller, and Houde (1974).

Preanal Length (PAL): Tip of the snout to the end of the anus measured along the midline of the body. This measurement is

also used to describe the location of the anal fin for specimens that have shown development of the anal fin complex.

Predorsal Length (PDL): Tip of the snout to break in the finfold for specimens in the yolksac or very early preflexion stage of development: Tip of the snout to the origin of the first dorsal ray measured along the midline of the body for fish that are exhibiting dorsal fin development. If dorsal rays were not evident then the measurement was made at the origin of the first dorsal radial bone.

Head Length (HL): Tip of the snout to the posterior margin of the auditory vesicle in yolksac and early preflexion larvae: Tip of snout to posterior margin of opercular membrane and bone when development was evident.

Eye Diameter (ED): Horizontal diameter between the anterior and posterior edges of the fleshy orbit.

Body Depth (BD): Vertical height of the body measured at the origin of the first dorsal ray.

All morphometrics were taken on the left side of the fishes body. Damaged specimens were not utilized in this study.

Meristics

Meristics were taken from cleared and counterstained flexion and postflexion specimens as per the methods of Berry and Richards (1973). Counts were made of the following characters:

Myomeres:

Total myomeres

Predorsal myomeres

Preanal myomeres

Postanal myomeres

Fin Ray Counts:

Anal rays

Dorsal rays

Pectoral rays

Pelvic rays

Caudal Complex Counts:

Superior procurrent caudal rays

Inferior procurrent caudal rays

Superior principle caudal rays

Inferior principle caudal rays

Hypurals

Uroneurals

Epurals

Ural Plates

The sequence of caudal development was recorded by the following criteria: (1) Noting the smallest SL at which Alcian-blue reacted with the mucopolysaccarides in cartilage, and (2) tracing the development through the staining reactions of calcium with Alizarin-red s, indicating the ossification of cartilage into bone (J.J. Govoni, personal communication[1]).

Line drawings of representative specimens were made with a binocular dissecting microscope and camera lucida.

Data Analysis

Measurements were analyzed using the Statistical Package for the Social Sciences (SPSS) Linear regression program (Nie et al. 1976). Notochord-standard length was the independent variable and each associated measurement was used as a dependent variable for generating the regression equations of the morphometric variables.

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[1] John J. Govoni, Ph.D., National Marine Fisheries Service, Beaufort, N.C.

Procedures in the Statistical Analysis System (SAS) for the univariate t-statistic, analysis of covariance, and the multivariate analysis of variance (MANOVA) were used to examine the relationship of cultured and wild postflexion A. sapidissima morphometrics (Helwig et al. 1979). The analysis of these two populations was completed over a comparable range of standard lengths.

RESULTS

MORPHOLOGY

Morphometrics and body proportion ratios for larval A. sapidissima are presented in Tables 1 and 2. A. sapidissima body proportions change during ontogeny with the most abrupt changes occurring during early development. Head length, snout length, eye diameter and body depth exhibited a curvilinear relationship with increasing notochord-standard length. Preanal length and predorsal length exhibited a linear relationship with increasing notochord-standard length.

The most obvious change in larval development is the gradual acquisition of a more robust and deeper body. This change from a thin-elongated body is typical of clupeoids in the western North Atlantic (Richards et al. 1974).

Total Length and Notochord-Standard Length

Notochord-standard length (SL) was used to examine development of A. sapidissima with respect to the other morphometric data. A regression equation was calculated for the relationship between total length (TL) and SL (Figure 4). Heuristic inspection of Figure 4 and a high coefficient of determination ($r^2 = 0.998$) indicated a strong linear relationship. Notochord-standard length fluctuated between 97.5% and 92.4% of the TL for larva measured. There were no changes in the TL and SL relationship between 8 and 13 mm, where it remained at 96%. The most abrupt changes in this relationship were seen in the early postflexion stage of development, between 18 and 23 mm, when the SL decreased from 97.2% to 95.7% (Table 2). The ratio averaged 96.5% for larva less than 15 mm and 95.5% for larva between 15 and 31 mm. The decrease in body proportion for the SL and TL relationship is related to the caudal fin development, particularly

notochord flexure between 12 and 15 mm, along with development of the first and second hypural plates.

Preanal Length

The preanal length (PAL) for larval A. sapidissima exhibited a steady decrease from 95% for 8 mm larvae to 65.4% for 31 mm larvae (Table 2). A regression equation was calculated for the relationship between PAL and SL. Visual inspection of Figure 5, along with a high coefficient of determination (r^2 = 0.969), tends to indicate a linear relationship. At 18 mm SL the PAL/SL ratio is invariate (Figure 5). It is at this length that A. sapidissima is undergoing the transformation from the flexion to postflexion stage of development.

The most striking change in this relationship was seen between 23 and 27 mm TL (69.1% and 65.8%). Over this TL range the gut was shortening and transformations to the juvenile stage (postflexion) became evident, which tends to account for the decrease in the PAL and SL relationship.

Predorsal Length

Predorsal lengths (PDL), measured on A. sapidissima larvae from the snout to the origin of the first dorsal radial and/or ray, decreased with increasing SL (Tables 1 and 2). There appears to be three distinct size intervals where the PDL decreases (Figure 6). Little change was evident between 8 and 14 mm where the predorsal length averaged 64.9% of the SL. Predorsal lengths averaged 56.8% of the SL for specimens between 15 and 20 mm and 45.3% of the SL for larvae between 21 and 31 mm.

A regression equation was calculated for the PDL/SL relationship (Figure 6). This relationship appears to be essentially linear, as indicated by heuristic examination of Figure 6 and a high coefficient of determination (r^2 = 0.964).

The dorsal fin migrates forward as dorsal rays develop and SL increases. This accounts for the decrease in predorsal body proportions from 66.7% to 43.6% of the SL (Table 2). This decrease is common for clupeoid larvae (Ahlstrom 1968; Houde et al. 1974; Jones et al. 1978).

Head Length

Larvae of A. sapidissima are relatively big-headed in comparison to their thin non-robust body in the preflexion and flexion stages. Head development is prominent in larvae between 8 and 11 mm. Five branchial arches, jaws, and 2 pairs of recurved teeth in the lower jaw are evident in larvae this size.

Head length (HL) averages 14.7% of the SL between 8 and 11 mm (Table 2). At 12 mm, HL increases to 17.0% of the SL. An increase of 1.2%, from 17.0% to 18.2%, is evident in the HL/SL relationship for larva between 12 and 17 mm. The HL/SL relationship is not as evident in late flexion and postflexion larvae because the body becomes deeper bodied and more robust, thus masking HL proportions. Head length increases from 20.1% to 27.5% of the SL in larvae between 18 and 31 mm.

A regression equation was calculated for the HL and SL relationship (Figure 7). Heuristic examination of Figure 7, along with a high coefficient of determination ($r^2 = 0.972$), at first tended to indicate a linear relationship between the HL and SL morphometrics. Figure 7 has an inflection point at about the transformation between the flexion and postflexion stages (18 mm SL) where the HL/SL relationship may exhibit curvilinear growth. Fitting the data to the model ($HL = aSL^b$) for a curvilinear growth curve (Sokal and Rohlf 1969) produced a higher coefficient of determination ($r^2 = 0.992$). The HL/SL relationship may indeed exhibit a curvilinear relationship; however, more data is needed beyond 30 mm SL to fully explore this relationship.

Eye Diameter

Horizontal eye diameters (HED) averaged 4.3% to 4.7% of the SL for

specimens 8 to 13 mm (Table 2). A slight increase in proportional eye diameter was seen in the flexion stage, between 14 and 18 mm, where eye diameter averaged 5.2% to 5.7% of the SL. A rapid increase in proportional eye diameter from 6.8% to 8.9% of the SL, between 20 and 31 mm, was evident for postflexion larval A. sapidissima.

Heuristic inspection of Figure 8 showed that a curvilinear relationship exists between HED and SL. Both HED and SL were log transformed to fit the linear regression of these two morphometric variables, and a coefficient of determination was calculated (r^2 = 0.973; Figure 8). Eye diameters are variable for a given size interval; for example, at 23 mm SL they varied between 1.60 and 1.86 mm, and at 29 mm SL between 1.72 and 2.00 mm (Figure 8). Most of the variability occurs from 19 to 31 mm SL, right after the transformation from flexion to postflexion larvae (Figure 8). Very little variation occurred in the preflexion and flexion stages (6 to 18 mm SL).

Snout Length

Snout length (SNTL) increased from 2.4% to 6.4% of the SL for larval A. sapidissima between 8 and 31 mm. Proportional snout lengths remained fairly constant between 8 and 18 mm. The greatest change in SNTL was seen between 18 and 20 mm, where it increased from 3.8% to 5.1% of the SL. Snout length, like HED, is highly variable between 19 and 31 mm (Figure 9). In the preflexion and flexion stages (8 to 17 mm) SNTL length remains fairly constant, with little variation for each individual size interval (Tables 1 and 2; Figure 9). The widest variation was seen in postflexion larvae at 23 mm and 29 mm (Table 2; Figure 9).

Snout length exhibits curvilinear growth with respect to SL (Figure 9). Both SNTL and SL were log transformed to fit a linear relationship between SNTL and SL and a coefficient of determination value (r^2 = 0.964) was also calculated (Figure 9). Snout lengths are variable for a given size range in the postflexion stage (Figure 9). Most of the variability occurs in postflexion larvae, between 19 and 31 mm SL, while

very little variation occurs between 6 and 18 mm SL (preflexion and flexion larvae).

Body Depth

Body depth (BD), measured at the origin of the first dorsal radial and ray, exhibited a curvilinear relationship with respect to SL. A regression equation for transformed measurements and a coefficient of determination (r^2 = 0.977) is presented in Figure 10. Body depth, second to PDL, showed the greatest proportional change from 7.2% to 21.5% of the SL (Table 2). The change in proportional BD is gradual for larval A. sapidissima between 8 and 20 mm (Figure 10). An increase from 12.5% to 17.0% of the SL is the most striking change in BD for larva between 20 and 23 mm (Table; Figure 10).

Increases in body depth indicate corresponding increases in body weight and body volume. As the SL and BD increase, the body shape becomes more streamlined, changing from a thin rod-like shape to a deep-bodied streamlined shape in A. sapidissima (Figures 14, 15, 16, 17, 18, 19).

MERISTICS

Myomeres

Myomere counts have been shown to be useful for identifying clupeoid genera (Ahlstrom 1968; Houde, Richards, and Saksena 1974). The total number of myomeres counted on larval A. sapidissima ranged from 54 to 58; most of the larvae had 55 or 56 myomeres. The number and distribution of myomeres relative to body morphology is shown in Table 3.

The distribution of myomeres was examined for larval A. sapidissima in relation to predorsal and preanal body measurements. Predorsal myomeres decreased in number with increasing SL. As the dorsal fin migrates forward and SL increases the predorsal myomere count decreases. Overall, predorsal myomere counts decreased from a mean of 33.9 to 21.0 for the larvae examined (N = 52). The most striking change in predorsal myomere counts was in the 12.1 to 18.0 mm SL size interval where a reduction of 5.2 in the mean number of predorsal myomeres was evident (Table 3). There is, however, considerable variation in predorsal myomere counts for all size intervals, as shown in Table 3.

Counts for preanal myomeres decreased with increasing SL and decreasing PAL (Table 3). There was a decrease in the mean number of preanal myomeres from 48.4 to 38.5 for the larvae examined (N = 52). This decrease parallels the shortening of the gut as the SL increases.

The mean number of postanal myomeres increases with the shortening of the gut and increasing SL. An increase from a mean of 12.3, between 8 and 9 mm, to a mean of 15.6 postanal myomeres, for larvae between 15 and 18 mm SL, was evident for the larvae examined (N = 40; Table 3). No information is available in this study for postanal myomere counts in larval A. sapidissima greater than 18.0 mm SL.

Fin Development

Median and paired fin development is indicated in Tables 4 and 5

for both hatchery cultured and field sampled specimens. A summary of cultured specimens fin development is present in Table 6. Development of the median fins (dorsal, anal, and caudal), including ossification of rays, is first evident in larval A. sapidissima between 9.0 and 12.5 mm SL. Median fin development is completed between 17 and 21 mm SL. Paired fin (pectoral and pelvic) development is not truly evident in larval A. sapidissima until larvae are in the late flexion-early postflexion stages, between 15 and 23 mm SL. Development of the paired fins was complete when larvae were between 23 and 27 mm SL (Table 6).

Dorsal Fin

The dorsal fin of A. sapidissima exhibits the earliest development of all fins. Dorsal fin radials first appear in larvae between 8.0 and 9.0 mm SL (Table 6). Radials appear as buds and are not fully developed. This is around the length that the yolksac is absorbed in larval A. sapidissima First evidence of dorsal fin ray formation is seen in larvae between 9.0 and 9.25 mm SL, where 6 to 8 unossified rays are evident (Tables 4 and 6). The number of dorsal fin rays increases with increasing SL: 7 to 10 rays are evident for larvae 9.5 to 11.5 mm SL, while 11 to 15 dorsal fin rays are evident between 11.5 and 13.5 mm SL (Table 4). A. sapidissima acquire their full complement of dorsal fin rays (17 to 20) between 17 and 20 mm SL (Tables 4 and 6).

Anal Fin

Anal fin development first is evident in larval A. sapidissima at 11.0 mm SL with the formation of anal radials (Table 6). Anal fin radials first appear as buds and are not fully developed. Rays in the anal fin are evident at 11.8 mm SL. Development proceeds rapidly with a full complement (19 to 23 fin rays) of unossified and early ossified anal fin rays between 19 and 21 mm SL.

Caudal Fin Complex

A. sapidissima has a complex caudal skeleton. The adult caudal

skeleton of A. sapidissima has the following structures: 6 hypurals, 1 parhypural attached to the first preural vertebra and next to the 1st hypural, 3 uroneurals, 2 ural vertebra, a neural arch and neural spine attached to the first preural vertebra, 2 epurals, 10 superior principal caudal rays, 9 inferior principal caudal rays, 8 superior procurrent rays, 7 inferior procurrent caudal rays. Separation between the superior and inferior principal caudal rays is evident between the second and third hypural, where there is a discernable gap.

The developmental sequence for the various components of the caudal complex of A. sapidissima is from the first appearance of cartilaginous structures to a gradual ossification and fusion of parts of the caudal complex. The criteria used to place larva into the proper stage of development are similar to that described by Tucker (1978). Terminology used for caudal osteology follows that of Mead (1963) and Lagler et al. (1962). Description of the sequence of caudal complex (Figures 11 and 12) development is based on nineteen selected counterstained specimens.

Preflexion

Larvae between hatch and 9.5 mm SL had a straight notochord (no flexure) and showed no evidence of any support structure (hypurals, uroneurals, neural or hemal spines) development (Figure 11a). Early caudal formation and development (late preflexion stage) is evident in larvae between 9.8 mm and 11.3 mm SL. The notochord is straight and one incipient parhypural and one to three incipient hypurals have started development (Figure 11b). The hypurals and parhypural first appear stained with alcian-blue, which reacts with the mucopolysaccarides in cartilaginous structures. There is some incipient caudal fin ray development (Table 4). These rays also stained with alcian-blue, indicating non-calcified cartilaginous structures.

Flexion

Notochord flexure starts in larval A. sapidissima between 11.5 and

12.6 mm SL, and is completed by 18 mm SL. A specimen 12.1 mm SL exhibited the following characteristics of early notochord flexure. The posterior end of the notochord was beginning to tip up dorsally. One parhypural and the first four hypurals (numbered ventral to dorsal) were formed. The anterior portion of the first, second, and third hypurals and parhypural absorbed alizarin-red s stain, indicating that the structures were ossifying. The fourth hypural and the posterior portion of the first three hypurals and parhypural absorbed alcian-blue stain. These stains were easily distinguished with sharp differentiation between calcified and non-calcified portions of the structure. A cartilaginous hemal spine was also evident in the caudal osteology of this specimen. Another specimen, 13.2 mm SL, exhibited the following characteristics for a larvae in mid-flexion (Figure 11c). The posterior end of the notochord was curved dorsally and then flattened into an S shape. Five hypurals were distinct, with hypurals 1, 2 and 3 absorbing alizarin-red s in the anterior portion of the structure. Both hemal and neural spines were present, absorbing both alcian-blue and alizarin-red s stain. The first evidence of the first uroneural appeared in this specimen.

Late flexion larval A. sapidissima are characterized by complete flexure of the notochord, and evidence of segregation into the uroneurals and ural vertebra (Figure 11d). A cartilaginous sixth hypural plate is evident, absorbing alcian-blue stain. Two slightly fused epural bones are evident, along with the first formation of the neural arch. Both the neural arch and epurals appear as cartilage as indicated by reaction with alcian-blue. There appears to be a distinct cartilaginous fusion between the hemal spine and the parhypural bones (Figure 11d).

Postflexion

Postflexion larval and juvenile A. sapidissima show complete separation between the ural vertebra and preural vertebra (Figure 12). Ural and preural vertebra completely absorbed alizarin-red s stain indicating ossification of the structures. The hypurals, neural and hemal spines, neural arch, and the epurals all absorbed alizarin-red s and alcian-blue

stains. The epurals no longer were fused. The third uroneural was stained with alcian-blue. These structures do not appear to completely ossify until well into the juvenile stage of development. A field sampled specimen 48.0 mm standard length showed complete alizarin-red s absorption in the hypurals, ural and preural vertebrate and the neural arch. The neural and hemal spines, and parhypural exhibited proximal end absorption of alcian-blue to preural vertebra 1-4. The two epural bones had absorbed alcian-blue at both the anterior and posterior tips of the structures, with alizarin-red s absorption in the middle.

Pectoral Fin

Pectoral fin development in A. sapidissima is evident at hatch in the form of a pectoral fin fold and cartilaginous support structures (Figures 13, 14). Incipient pectoral fin rays are also evident in yolksac larvae; however, these rays would not stain with alcian-blue or alizarin-red s, but were outlined under low powered light microscopy (25X). The first evidence of stained (absorbing alcian-blue) pectoral fin development was seen in the flexion stage, between 13.8 and 19.4 mm SL (Tables 4 and 6; Figures 15, 16, 17).

Development of the pectoral fin appears to be slow when compared to the other fin development characteristics in Table 6. There is a 5.6 mm range of SL over which cartilaginous pectoral fin rays first absorb alican-blue stain. Development is complete in the postflexion stage, between 23.8 and 25.7 mm SL, with a full complement of 14 to 18 pectoral fin rays.

Pelvic Fin

The pelvic fin is the last of the five median and paired fins to start and complete development (Table 6). Pelvic fin development is first evident in larval A. sapidissima around the transformation from flexion to postflexion larvae, between 17.0 and 19.0 mm SL. The pelvic fin basipterygium first appeared during this size interval. The first

evidence of pelvic fin ray development is between 19.2 and 19.6 mm SL (Tables 4 and 6). Development is complete between 25.0 and 27.0 mm SL, with a full complement of eight to ten pelvic fin rays.

PIGMENTATION

The distribution of melanophores on A. sapidissima appears to be similar to that of other clupeoid larvae found in Chesapeake Bay tributaries and the western North Atlantic (Jones et al. 1978). There is some variability in the pigmentation patterns among individuals in any given size interval; however, this variation is due in part to individual chromatophores and melanophores existing in a contracted or expanded state. The specimens illustrated in Figures 13-19 indicate the general pattern of pigmentation typical of the A. sapidissima specimens collected in this study.

Head Region

Preflexion, newly-hatched, A. sapidissima have very few melanophores on the snout and over the brain. A newly-hatched specimen, 8.2 mm SL, had one stellate melanophore on the tip of the snout and two others in a straight line, spaced at equal intervals, toward the anterior end of the eye. The eyes in this specimen and all the specimens sampled were fully pigmented by 9.5 mm SL (Figure 13). Three to five melanophores were present over the brain of a specimen 10.4 mm SL (2 days after hatch). A small, but distinct, line of melanophores are present above the yolksac, over the pectoral symphysis and heart in specimens 9.3 to 10.5 mm SL (Figure 13). These melanophores are very small, and difficult to detect. Melanophores over the yolksac were not present in specimens 10.8 to 11.3 mm SL indicating that they had apparently contracted or migrated (Figure 14).

The number of melanophores on the snout and brain increases with increasing SL. A 10.9 mm SL specimen (Figure 14) showed an increased number and density of melanophores on the snout. A line pattern of pigmentation is developed dorsally from the snout up the midline of the skull and over top the brain in larvae between 10.9 and 28.5 mm SL (Figures 14-19). This pigmentation was comprised of mostly stellate melanophores.

The pigment pattern associated with the area posterior to the fleshy orbit of the eye, and anterior to the opercular is variable in larval A. sapidissima. The density and number of melanophores around the eye increased up to around 22 mm SL. Larvae in the 15 to 18 mm SL range showed most of this pigment just posterior to the fleshy orbit of the eyes, with no melanophores over the opercular bone (Figures 16 and 17). Larvae greater than 20 mm (Figures 18 and 19) exhibited distinct melanophores from the fleshy orbit over top of the opercular bone. A substantial number of the specimens examined, greater than 20 mm SL, showed no increase in the actual number of melanophores. Instead, this pigment appeared to migrate, and in some cases contract, from the fleshy orbit of the eye onto the opercular bone. Field sampled specimens greater than 28 mm showed a reduced number and density of pigment just posterior of the fleshy orbit of the eye, and a more concentrated number just anterior the tip of the opercular bone.

Gut, Trunk and Fin Region

Yolksac, preflexion, A. sapidissima have a series of very small, distinct, melanophores along the dorsal surface of the gut. These melanophores remained distinct on the larvae up to about 18 mm SL (Figures 14, 16, 17). Approximately two days after hatch pigmentation was evident on the ventral surface of the gut. This pigment was in a dense pattern of short dash shaped melanophores that gave the appearance of a solid line by 15 mm SL (Figure 16). After 15 mm SL ventral gut pigmentation contracted from a solid line pattern to a series of spaced melanophores (Figures 16 and 17).

As the larvae developed into the postflexion and juvenile stages of development gut pigmentation became increasingly difficult to detect because of the added body tissue and weight. Shortening of the gut, with increasing SL, is seen in conjunction with the formation of larger distinct stellate melanophores along the dorsal gut surface (Figure 17). There is also a denser concentration of stellate melanophore at the anus in postflexion and juvenile A. sapidissima.

Pigment developed along the anal fin base at 15 mm SL where one to three stellate melanophores were found in a series of specimens 15 to 16 mm SL (Figure 16). The number of anal fin base melanophores increased to between 14 and 20 for 18 to 20 mm SL larvae (Figure 17). Postflexion A. sapidissima (Figure 18) had approximately 22 to 26 stellate melanophores in a straight line pattern over the radials of the anal fin. This line of pigmentation was continuous from the anus, where a dense concentration of melanophores was found, to the caudal peduncle, were pigmentation associated with the caudal fin was evident.

Pigment is found at the base of the dorsal fin over the developing radials, in larval A. sapidissima at 12 mm SL. From zero to five small melanophores were counted on a series of 11.8 to 13 mm SL specimens. The number and density of melanophores associated with the dorsal fin increased as the fish grew and the dorsal fin migrated forward. Larvae in the 15 to 18 mm SL range have 10 to 19 stellate melanophores over the radials of the dorsal fin (Figures 16 and 17). A. sapidissima larvae greater than 20 mm SL have a stellate melanophore directly over each of the radials of the dorsal fin (Figures 18 and 19); there are 20 radials with at least one, in most specimens examined more than one, melanophore at the base of the fin (Table 6 for the dorsal fin data).

There are a continuous pair of pigmentation stripes from the eye to the caudal peduncle along the dorsal midline of larval A. sapidissima. These stellate melanophores are less densely distributed between the brain and the first dorsal radial than between the last dorsal radial and the caudal peduncle. The paired melanophores anterior to the dorsal fin are distinct, and appeared as two lines, while posterior to the dorsal fin the melanophores are still paired, but coalesce into a single line.

Large stellate melanophores first appear on the posterior end of the lateral line in A. sapidissima at 18 mm SL (Figure 17). Between 11 and 15 melanophores are evident during this transition phase between flexion and postflexion larvae. In some of the specimens examined, in

the 18 to 20 mm SL range, pigment was in pairs; one directly above and one directly below the lateral line (Figure 17). Between 35 and 62 large stellate melanophores were counted on specimens greater than 20 mm SL along the lateral line posterior to the dorsal fin.

Pigment first appeared as very small light chromatophores along the lateral line anterior the dorsal fin and posterior the opercular bone in specimens 13 to 16 mm SL. These cells expanded into distinct stellate melanophores in larger specimens (Figure 18). The number of melanophores that could be counted along the lateral line ranged from seven to 23 in specimens 17.7 to 21.9 mm SL; more than 50 melanophores were counted for larvae greater than 23 mm SL (Figure 18). Stellate melanophores in the larger postflexion larvae (greater than 25 mm SL) contracted into small indistinguishable melanophores along the lateral line (Figure 19).

Caudal Region

Newly-hatched A. sapidissima did not have pigment associated with the notochord posterior to the anus (Figure 13). Pigment first appeared on the dorsal tip of the notochord at 9.8 mm SL with one to four small melanophores. At 10.9 mm SL (Figure 14) pigment was present as eight small melanophores on the dorsal tip, and four small melanophores on the ventral tip of the notochord.

Melanophores associated with the caudal region appeared to have migrated toward the anus in larvae between 11 and 13 mm SL. The number and density of melanophores concentrated at the end of the anus increased during this length interval (Figure 3). Pigment still appeared in the caudal region as larger distinct stellate melanophores; however, the number of melanophores remained fairly constant between three and seven for larval between 11 and 13 mm SL.

Pigment density increased rapidly in the caudal region in larvae larger than 15 mm SL (Figures 16, 17, 18, 19). Melanophores migrated onto the developing caudal rays from the caudal peduncle region, and

large stellate melanophores outlined the edge of the caudal peduncle (Figure 17).

Pigmentation reached its greatest density in larva 23 to 25 mm SL (Figure 18). The number of melanophores increased and became more concentrated in postflexion and juvenile A. sapidissima. Larvae greater than 25 mm SL exhibited contraction in size of caudal stellate melanophores which became difficult to distinguish individually (Figure 19).

COMPARATIVE MORPHOLOGY

Morphometrics for both wild and cultured populations of postflexion A. sapidissima were comparatively analyzed using univariate and multivariate statistical techniques to test for differences in the morphology of the two populations. Three types of tests were used in the analysis. A students t-test and F value were calculated to examine the morphometric means and variances (i.e. the variability in the population) of the wild and cultured samples. Analysis of covariance was used to examine the linear regressions, of each dependent morphometric measurement (PAL, PDL, HL, SNTL, HED, BD) with the independent variable SL, and test the hypotheses that the homogeneity of slopes ($\beta_1 = \beta_2$) and changes in elevation ($\alpha_1 = \alpha_2$) are not significantly different between wild and cultured populations (Snedecor and Cochran 1967). The third technique applied was a Multivariate Analysis of Variance (MANOVA), used to test the hypothesis of no overall effect due to the wild and cultured population treatments (Pimental 1979; Tatsuoka 1971; Cooly and Lohnes 1971). Information summarizing the student's t-test and analysis of covariance are in Appendicies 2 and 3. A summary of the MANOVA is presented in Appendix 4.

Overall, results of the univariate and multivariate analytical techniques used indicated that there was no significant difference between wild and cultured morphometric variables used in this study.

Comparison of Morphometric Means and Variances

The F test for equality of variances was significant for the SL, PAL, HL, and BD measurements. This indicated that there was some variability between the distributions of the wild and cultured samples for these particular postflexion morphometrics. Satterthwaites (Dunn and Clark 1974) approximation for degrees of freedom was calculated and an approximate t statistic (t*) was found for each set of means (Appendix 2). In all the above cases, t* was highly non-significant. Therefore, apparent mean differences were attributed to sampling error.

F-tests indicated homogenity of variances for the PDL, SNTL, and HED measurements for wild and cultured populations. The t statistic was nonsignificant for the SNTL and HED morphometrics (Appendix 2). These results also show that there appeared to be no individual mean difference in cultured and wild postflexion A. sapidissima for the SNTL and HED morphometrics.

The t statistic for comparison of wild and cultured predorsal length means was marginally significant ($P < .05$). This difference in means could be related to the anterior migration of the dorsal fin, along the dorsal midline of the body.

Analysis of Covariance

The SAS General Linear Models procedure for analysis of covariance was utilized to examine the linear regressions of each dependent morphometric variable and the independent variable SL, and test the hypotheses that the slopes and elevations of the wild and cultured specimens are equal ($\beta_1 = \beta_2$ and $\alpha_1 = \alpha_2$). Log transformations were made on the HL, SNTL, HED, and BD by SL morphometric comparisons. This was done to account for the curvilinear relationship found earlier in the study. Use of log transformations strengthened the coefficient of determination values (r^2) by an average of 2% for each comparison from the untransformed data.

An F test was first made on the analysis of covariance model ($H_o:B_o = 0$) to see if the specified model would be able to account for any differences in the regressions (Appendix 3). In all cases the model specified was significant, indicating that analysis of covariance would detect differences in the linear regressions of each wild and cultured dependent variable on SL. Coefficient of determination (r^2) values, a measure of the dependency of the ordinate variables on SL, ranged from 56.7% for HED to 85.0% for HL.

Scatterplots of the wild and cultured regressions are presented in Figures 20 to 25. The analysis of covariance test for the homogeneity of slopes was nonsignificant ($P < .05$) for each set of regressions presented in Figures 20-25 and Appendix 3. This indicated that each morphometric variables rate of change with SL was not significantly different for postflexion cultured and wild A. sapidissima. Thus, the body proportion ratios of wild sampled A. sapidissima are apparently not different than those presented in Table 2 for cultured postflexion larvae.

Analysis of covariance also indicated that the difference in elevations (adjusted means) of each line was not significantly different ($\alpha_1 = \alpha_2$) when computed for each wild and cultured dependent morphometric variable (Appendix 3). This indicated that the body proportion ratios, for each individual morphometric variable, were apparently not different from the wild and cultured populations at the onset of the postflexion stage of development.

The linear regressions of each wild and cultured morphometric dependent variable appeared to indicate no significant difference between the body proportion ratios of the two populations, and that the rate of change for each variable appeared similar throughout the postflexion stage of development examined in this study.

Multivariate Analysis of Variance (MANOVA)

A MANOVA was utilized to test the hypothesis of no overall group effect between the wild and cultured populations of postflexion A. sapidissima. The treatments (columns) in this study were the wild and cultured groups, while the blocking (rows) were the morphometric variables SL, PAL, PDL, HL, SNTL, HED, and BD. Thus, a difference between the two populations was tested in $k = 5$ space. The Hotelling-Lawley trace, Pillai's trace, Wilks criterion, and Roy's maximum root criterion were tests of significance used to examine the hypothesis of no overall effect between wild and cultured morphometric variables (Appendix 4).

The relative sensitivities of the Hotelling-Lawley trace and Wilk's criterion are about equal towards examining the significance of the null hypothesis (Schatzoff 1966). In both cases, the test of the null hypothesis of no overall group effect was highly nonsignificant ($P < 0.05$). Thus, the eigenvalues (λ_{SL}, λ_{PAL}, λ_{PDL}, λ_{HL}, λ_{SNTL}, λ_{HED}, λ_{BD}) of the SSCP matrix are smaller than the specified centile points of $\alpha = .05$ for the Hotteling-Lawley trace (τ) and Wilks criterion (Λ). Pillai's trace of the distribution of the morphometric variables between the wild and cultured treatments is similar to that of the Hotelling-Lawley trace, and was also nonsignificant. The results of these tests of the MANOVA indicate that the combined effect of the morphometric variables measured for each of the wild and cultured populations was not significantly different.

Roy's maximum root criterion is not as sensitive a test as the previous three, except when the difference between the treatments is concentrated in one of the morphometric variables (Schatzoff 1966; Tatsuoka 1971). This test was found to be highly significant ($P > 0.05$). Examination of each variable block shows that PDL was the only variable that had a significant difference between the wild and cultured treatments (Appendix 4). This difference in the PDL is again related to the position which the dorsal fin migrates along the dorsal midline of the body. Roy's maximum root criterion magnifies the differences in the PDL means found using the t statistic.

Overall, results of the MANOVA indicate that there was no difference in the combined effects of the morphometric variables between the wild and cultured populations of postflexion A. sapidissima.

DISCUSSION AND CONCLUSIONS

Morphology

Morphological and body proportion development for larval Alosa sapidissima has been described using the dynamic approach of Ahlstrom, Butler, and Sumida (1976) and Moser and Ahlstrom (1970). Examination of the body proportion ratios shows that during ontogeny the PDL and PAL by SL ratios are negatively allometric with increasing SL, while the HL, SNTL, HED, and BD by SL ratios increase isometrically with increasing SL.

Morphological development presented in this study was a dynamic summary of larval A. sapidissima morphology from yolk absorption through the postflexion stage of development. Hildebrand (1963) described proportional ratios on juvenile and adult A. sapidissima, 29 to 475 mm SL, while this study concentrated on describing morphological development in the larval stages. Thus, a complete morphological description, during all stages of the life history, is now available for A. sapidissima.

Information pertaining to the morphology of larval A. sapidissima presented herein reinforces the summary information presented in Jones et al. (1978), Lippson and Moran (1974), and Mansueti and Hardy (1967). In addition, the body proportion ratios given in this study detail the ontogenic changes in body development that were previously unavailable in the literature. The earliest studies on A. sapidissima larval morphology by Hildebrand and Schroeder (1928), and Leim (1924), gave morphometric body proportions for selected sizes of larva, but they failed to adequately trace the ontogenic changes associated with larval development. Recent studies on the early development of A. sapidissima by Chittenden (1969), Marcy (1976), and Watson (1968) presented results that adequately describe the development and ontogenic changes associated

with egg and yolksac larva development. Morphology and development of preflexion and flexion larvae appears to be incomplete in these studies, because (1) field sampling techniques utilized did not adequately sample preflexion and flexion larvae, or (2) total mortality was experienced in the cultures used before the desired size range was sampled.

The culture techniques employed in this study (Blair 1976) provided adequate samples to describe the morphological development of A. sapidissima over the standard length range that was previously void (yolksac absorption to the postflexion stage). In addition, a complete description of morphological development and body proportion ratios is now available from hatch through the adult stage. A combination of this study, Hildebrand (1963), Chittenden (1969), and Marcy (1976) provides a complete synopsis of the morphology and development for the egg, larva, and adult stages in the life history of A. sapidissima.

Meristics

Meristic development for larval A. sapidissima (Wilson) has been described by following the sequence of cartilage investment and the ossification of rays and bones in the paired and median fins. Additionally, the distribution of myomeres relative to the body morphology has been described . This provides additional information useful in larval identification of A. sapidissima.

The range of preanal myomeres reported for cultured larval A. sapidissima in the present study varies from that previously reported for A. sapidissima (Jones et al. 1978, Lippson and Moran 1974, Mansueti and Hardy 1967). Jones et al. (1978) reported a range of 44-50 ($\bar{x}$ = 47) preanal myomeres between 9.0 and 12.9 mm SL; Lippson and Moran (1974) report 41-47 between 6 and 14 mm SL, and Mansueti and Hardy (1967) reported 43-47 preanal myomeres up to 13 mm SL (Table 7). These myomere ranges are lower than those determined in the present study over comparable length ranges (Table 3).

The anterior myomeres can be difficult to discern in A. sapidissima because they are very crowded in the early stages of development (i.e. 8 to 10 mm SL range). Care was taken in this study to intensify the myomeres by immersing each larva in glycerin. Berry and Richards (1973) state that myomere counts can be distorted by crowding in the anterior region; the use of glycerin improves the reliability of myomere counts.

Both this study and that of Mansueti and Hardy (1967) reported a decrease in preanal myomere count with ontogeny and shortening of the gut, while maintaining the same range in total myomere number (Tables 3 and 7). Jones, et al. (1978) did not report a decrease in preanal myomeres with shortening of the gut. Rather they indicated an increase in the mean number of preanal myomeres (Table 7). Jones et al. (1978) information is based on Chambers et al. (1976), which compares the means and ranges of the preanal myomeres for larval clupeids (Table 7). Findings of this study and information reported in Mansueti and Hardy (1967) are different than that reported by Chambers et al. (1976) (Table 7). Small sample size (Chambers et al. 1976) may be the reason for the converse results between studies. Larval A. sapidissima, cultured for this study, exhibited a steady decrease in the ratio of PAL to SL, and in the mean number of preanal myomeres versus SL; these changes correlate with shortening of the gut throughout the flexion stage of development.

Ahlstrom (1968) proposed the use of dorsal fin position (PDL), and the relative number and difference between predorsal myomeres and preanal myomeres, as an accurate method for the identifying clupeid larvae. Predorsal myomere counts and ranges reported herein trace the anterior migration of the dorsal fin during ontogeny. The predorsal myomere count (Table 3) along with the predorsal body proportion ratio (Table 2) fulfils this previously void area that is useful for the accurate identification of larval A. sapidissima.

Fin Development

Meristics of developing paired and median fins have been described

for cultured larval A. sapidissima. Examination of sequentially sampled and counterstained larva has lead to a complete summary of the fin development sequence, and a determination of caudal fin osteological characters that allows for differentiating preflexion, flexion, and postflexion larval A. sapidissima.

The sequence of larval fin development and developmental osteology of A. sapidissima have not been previously studied. Hitchcock (1887, 1889) studied the osteology of adult A. sapidissima. Bigelow and Welsh (1925) postulated that fin formation may be completed in A. sapidissima by 20 mm SL. Nichols (1966) compared the fin ray meristics of several populations of juvenile A. sapidissima. Results presented by Nichols compare favorably with the number of rays in fins of fully developed cultured A. sapidissima (Table 7). The average number of dorsal (19), anal (21), and pectoral (16) fin rays counted on cultured larva and juveniles agrees with the means and frequencies of meristic counts made by Nichols (1966) on juvenile A. sapidissima from the York River, Virginia.

PIGMENTATION

Pigmentation and the sequence of change in pigment patterns have been described for larva from the preflexion through the postflexion stage of development. Ahlstrom (1968) noted that the atlas of Mansueti and Hardy (1967) did not discuss changes in pigment pattern associated with ontogeny. This study fills the gap in Mansueti and Hardy's (1967) discussion of A. sapidissima.

Hildebrand (1963), Jones et al. (1978), and Leim (1924) discuss the ventral pigmentation pattern seen from yolk absorption to approximately 13 mm SL. Indeed, this is one of the most important characteristics in identification of larval A. sapidissima. Ahlstrom (1968), however, points out that clupeids can be difficult to identify unless precaution is taken to note the sequence of changes in the larva. This is especially true with respect to pigmentation in larval A. sapidissima. Jones et al. (1978) and Leim (1924) note that specimens from freshwater are more

heavily pigmented than those in brackish water. This was confirmed in the present study by comparison of field and cultured specimens of larval A. sapidissima. Pigmentation is heavier on the head and dorsal trunk regions of freshwater cultured larvae than on native brackish water larvae.

The sequence of pigmentation described herein for A. sapidissima larvae can be used to identify A. sapidissima of freshwater origin. The pattern of ventral pigment described by Leim (1924) should be used when identifying larvae in the 10 to 13 mm SL range from samples collected in brackish water. There is a large amount of variability in the distribution of melanophores in freshwater cultured larva; therefore, special care should be taken when attempting to identify and confirm larval A. sapidissima collected in freshwater. Additionally, meristic characters, similar to those in Table 7, should be used in conjunction with pigmentation patterns to fully confirm identification of A. sapidissima from freshwater samples.

COMPARATIVE MORPHOLOGY

The section on comparative morphology between wild and cultured populations of postflexion A. sapidissima was completed to check for morphometric differences in the two populations of larvae. Had there been a significant difference in the wild and cultured treatments used in the MANOVA Pimentals (1979) suggestion that a discriminant function be calculated would have been followed to establish a set of classification criteria that would allow for differentiation between the wild and cultured populations.

In this study, there were no detectable morphometric differences in the two (wild and cultured) populations. The information presented on developmental morphology, including the body proportion ratios, can now be used as support for identification of brackish water larval A. sapidissima

Table 1. Morphometrics (in mm) for larval American shad, Alosa sapidissima, (Wilson)

Size Interval	N	STAT	TL	SL	PAL	PDL	PPL	HL	SNTL	HED	BD
8.00 - 8.99	9	$\bar{X}$	8.64	8.38	7.55	*5.60	-	1.23	.20	.36	.61
		SD	.174	.212	.230	-	-	.086	.026	.033	.055
		R	8.40 - 8.90	8.10 - 8.70	7.25 - 7.95	-	-	1.15 - 1.32	.15 - .23	.31 - .40	.51 - .70
9.00 - 9.99	39	$\bar{X}$	9.64	9.31	7.65	*6.24	-	1.37	.20	.40	.61
		SD	.265	.276	.201	.255	-	.090	.036	.047	.072
		R	9.00 - 9.99	8.60 - 9.67	7.13 - 7.96	5.72 - 6.60	-	1.17 - 1.62	.11 - .25	.31 - .51	.43 - .76
10.00 - 10.99	23	$\bar{X}$	10.43	10.01	8.12	6.60	-	1.46	.21	.46	.62
		SD	.360	.340	.196	.152	-	.114	.059	.053	.109
		R	10.00 - 10.97	9.50 - 10.60	7.81 - 8.57	6.30 - 6.94	-	1.25 - 1.71	.11 - .32	.33 - .55	.52 - .83
11.00 - 11.99	16	$\bar{X}$	11.36	10.97	8.79	7.09	*5.05	1.64	.26	.49	.70
		SD	.284	.298	.251	.183	.566	.130	.045	.031	.076
		R	11.02 - 11.72	10.60 - 11.42	8.41 - 9.25	6.88 - 7.38	4.65 - 5.45	1.40 - 1.81	.19 - .36	.43 - .51	.58 - .85
12.00 - 12.99	5	$\bar{X}$	12.49	12.05	9.52	7.63	**4.97	2.06	.32	.50	1.02
		SD	.242	.246	.313	.287	-	.073	.025	.024	.018
		R	12.17 - 12.71	11.78 - 12.28	9.55 - 10.28	7.25 - 8.00	-	1.96 - 2.10	.30 - .36	.46 - .52	1.01 - 1.05
13.00 - 13.99	2	$\bar{X}$	13.51	13.00	10.99	8.25	**5.57	2.34	.37	.61	1.26
		SD	.325	.707	.594	1.089	-	.332	.099	.014	.071
		R	13.28 - 13.74	12.50 - 13.50	10.57 - 11.41	7.48 - 9.02	-	2.10 - 2.57	.30 - .44	.60 - .62	1.21 - 1.31
14.00 - 14.99	2	$\bar{X}$	14.24	13.65	11.40	8.76	5.58	2.40	.44	.71	1.31
		SD	.042	.283	.212	.509	.198	.071	.035	.141	.014
		R	14.21 - 14.27	13.45 - 13.85	11.25 - 11.55	8.40 - 9.12	5.44 - 5.72	2.35 - 2.45	.41 - .46	.61 - .81	1.30 - 1.32

Table 1, Continued. Morphometrics (in mm) for larval American shad, Alosa sapidissima, (Wilson)

Size Interval	N	STAT	TL	SL	PAL	PDL	PPL	HL	SNTL	HED	BD
15.00 - 15.99	2	$\bar{X}$	15.75	15.34	12.22	8.98	**6.57	2.90	.54	.76	**1.54
		SD	.099	.148	.134	.078	-	.014	.085	.071	-
		R	15.68 - 15.82	15.23 - 15.44	12.12 - 12.31	8.92 - 9.03	-	2.89 - 2.91	.48 - .60	.71 - .81	-
16.00 - 16.99	4	$\bar{X}$	16.46	16.05	12.60	9.20	*6.30	3.00	.61	.74	1.74
		SD	.191	.130	.092	.114	.445	.065	.021	.045	.130
		R	16.24 - 16.63	15.93 - 16.17	12.50 - 12.72	9.07 - 9.31	6.00 - 6.81	2.96 - 3.06	.58 - .63	.70 - .80	1.62 - 1.86
17.00 - 17.99	1	$\bar{X}$	17.46	16.91	13.55	9.78	7.28	3.02	.55	.80	1.88
		SD	-	-	-	-	-	-	-	-	-
		R	-	-	-	-	-	-	-	-	-
18.00 - 18.99	1	$\bar{X}$	18.28	17.77	13.58	9.75	7.19	3.57	.68	1.01	1.96
		SD	-	-	-	-	-	-	-	-	-
		R	-	-	-	-	-	-	-	-	-
20.00 - 20.99	2	$\bar{X}$	20.47	19.63	13.96	10.83	8.55	4.25	1.01	1.16	2.46
		SD	.134	.417	.028	.544	.382	.070	.028	.064	.148
		R	20.37 - 20.56	19.33 - 19.92	13.94 - 13.98	10.44 - 11.21	8.28 - 8.82	4.20 - 4.30	.99 - 1.03	1.11 - 1.20	2.35 - 2.56
21.00 - 21.99	2	$\bar{X}$	21.05	19.44	13.56	9.40	-	4.21	1.11	1.33	2.39
		SD	.071	.042	.353	.332	-	.056	.035	.148	.028
		R	21.00 - 21.10	19.41 - 19.47	13.31 - 13.81	9.16 - 9.63	-	4.17 - 4.25	1.08 - 1.13	1.22 - 1.43	2.37 - 2.41
23.00 - 23.99	2	$\bar{X}$	23.26	22.28	15.41	10.43	-	4.91	1.26	1.73	3.80
		SD	.127	.537	.290	.184	-	.276	.226	.184	.163
		R	23.17 - 23.35	21.91 - 22.66	15.20 - 15.61	10.30 - 10.56	-	4.71 - 5.10	1.11 - 1.42	1.60 - 1.86	3.68 - 3.91

Table 1, Continued. Morphometrics (in mm) for larval American shad, Alosa sapidissima, (Wilson)

Size Interval	N	STAT	TL	SL	PAL	PDL	PPL	HL	SNTL	HED	BD
24.00 - 24.99	1	$\bar{X}$	24.28	23.13	15.00	11.41	-	5.62	1.33	1.75	4.04
		SD	-	-	-	-	-	-	-	-	-
		R	-	-	-	-	-	-	-	-	-
25.00 - 25.99	3	$\bar{X}$	25.24	23.98	15.01	10.20	**10.08	5.83	1.43	2.15	5.02
		SD	.110	.583	.775	.061	-	.105	.165	.165	.322
		R	25.15 - 25.36	23.46 - 24.61	14.15 - 15.65	10.13 - 10.25	-	5.73 - 5.94	1.32 - 1.62	1.96 - 2.26	4.68 - 5.32
27.00 - 27.99	1	$\bar{X}$	27.05	25.76	16.94	11.88	**11.63	6.76	1.83	2.07	5.39
		SD	-	-	-	-	-	-	-	-	-
		R	-	-	-	-	-	-	-	-	-
28.00 - 28.99	3	$\bar{X}$	28.34	26.61	17.39	12.60	12.46	6.76	1.78	1.99	5.37
		SD	.104	.079	.371	.051	.157	.157	.090	.055	.570
		R	28.27 - 28.46	26.52 - 26.67	16.99 - 17.72	12.54 - 12.64	12.28 -12.57	6.64 - 6.94	1.73 - 1.88	1.94 - 2.05	4.83 - 5.97
29.00 - 29.99	2	$\bar{X}$	29.54	28.17	18.57	12.22	12.17	6.61	1.55	1.86	5.46
		SD	.445	.487	.375	.430	.410	.156	.071	.198	.156
		R	29.22 - 29.85	27.82 - 28.51	18.30 - 18.83	11.93 - 12.50	11.88 -12.46	6.60 - 6.72	1.50 - 1.60	1.72 - 2.00	5.35 - 5.57
30.00 - 30.99	1	$\bar{X}$	30.93	29.50	19.50	**12.91	12.60	6.65	1.99	2.11	5.90
		SD	-	-	-	-	-	-	-	-	-
		R	-	-	-	-	-	-	-	-	-
31.00 - 31.99	1	$\bar{X}$	31.25	29.66	19.55	**12.93	12.68	8.15	2.12	2.64	6.38
		SD	-	-	-	-	-	-	-	-	-
		R	-	-	-	-	-	-	-	-	-
Totals	122										

$\bar{X}$ = Mean; SD = Standard Deviation; R = Range; * = Missing Values; ** = Only One Value; TL = Total Length; SL = Standard Length; PAL = Preanal Length; PDL = Predorsal Length; PPL = Prepelvic Length; HL = Head Length; SNTL = Snout Length; HED = Horizontal Eye Diameter; BD = Body Depth

Table 2. Morphometric ratios for larval American shad, Alosa sapidissima (Wilson): Based on Notochord-Standard Length

Size Interval	N	STAT	SL/TL	PAL/SL	PDL/SL	HL/SL	SNTL/SL	ED/SL	BD/SL
8.00 - 8.99	9	$\bar{X}$	.969	.900	*.667	.147	.024	.043	.072
		SD	.0010	.033	-	.011	.003	.004	.007
		R	.973 - .983	.856 - .940	-	.129 - .162	.018 - .028	.037 - .047	.059 - .086
9.00 - 9.99	39	$\bar{X}$	.965	.822	**.669	.147	.021	.043	**.066
		SD	.009	.013	.022	.011	.004	.005	.008
		R	.945 - .981	.796 - .866	.624 - .733	.123 - .163	.011 - .027	.032 - .053	.049 - .079
10.00 - 10.99	23	$\bar{X}$	.960	.817	**.658	.146	.022	.045	.063
		SD	.017	.019	.020	.012	.006	.005	.011
		R	.913 - .977	.790 - .851	.632 - .710	.126 - .156	.011 - .030	.035 - .055	.042 - .096
11.00 - 11.99	16	$\bar{X}$	.966	.802	.647	.149	.023	.045	.064
		SD	.015	.011	.008	.009	.004	.003	.006
		R	.915 - .975	.786 - .825	.633 - .665	.131 - .162	.018 - .032	.040 - .048	.053 - .076
12.00 - 12.99	5	$\bar{X}$	.965	.826	.633	.170	.027	.042	.085
		SD	.005	.019	.015	.006	.002	.002	.002
		R	.957 - .970	.802 - .847	.614 - .651	.162 - .178	.024 - .029	.038 - .044	.082 - .086
13.00 - 13.99	2	$\bar{X}$	.962	.846	.633	.179	.028	.047	.097
		SD	.030	.001	.049	.016	.006	.001	.001
		R	.941 - .983	.845 - .846	.598 - .668	.168 - .190	.024 - .033	.046 - .048	.096 - .097
14.00 - 14.99	2	$\bar{X}$	.959	.835	.642	.176	.032	.052	.096
		SD	.023	.001	.023	.001	.002	.009	.001
		R	.943 - .975	.834 - .836	.625 - .658	.175 - .177	.030 - .033	.045 - .058	.095 - .097

Table 2, Continued. Morphometric ratios for larval American shad, Alosa sapidissima (Wilson): Based on Notochord-Standard Length

Size Interval	N	STAT	SL/TL	PAL/SL	PDL/SL	HL/SL	SNTL/SL	ED/SL	BD/SL
15.00 - 15.99	2	$\bar{X}$	.974	.797	.586	.189	.035	.050	*.101
		SD	.016	.001	.011	.001	.005	.005	-
		R	.963 - .985	.796 - .797	.578 - .593	.188 - .190	.032 - .039	.046 - .053	-
16.00 - 16.99	4	$\bar{X}$	.975	.785	.573	.187	.038	.046	.109
		SD	.004	.012	.011	.004	.001	.003	.008
		R	.971 - .981	.773 - .798	.562 - .584	.181 - .191	.036 - .040	.043 - .050	.101 - .117
17.00 - 17.99	1	$\bar{X}$	.968	.801	.578	.179	.033	.047	.111
		SD	-	-	-	-	-	-	-
		R	-	-	-	-	-	-	-
18.00 - 18.99	1	$\bar{X}$	.972	.764	.549	.201	.038	.057	.110
		SD	-	-	-	-	-	-	-
		R	-	-	-	-	-	-	-
20.00 - 20.99	2	$\bar{X}$	.959	.712	.552	.217	.051	.059	.125
		SD	.014	.013	.016	.008	.003	.004	.010
		R	.949 - .969	.702 - .721	.540 - .563	.211 - .222	.050 - .053	.056 - .062	.118 - .132
21.00 - 21.99	2	$\bar{X}$	.924	.697	.483	.217	.057	.068	.123
		SD	.005	.016	.016	.002	.002	.007	.001
		R	.920 - .927	.686 - .709	.472 - .495	.215 - .218	.056 - .058	.063 - .073	.122 - .124
23.00 - 23.99	2	$\bar{X}$	.957	.691	.468	.221	.056	.078	.170
		SD	.018	.004	.003	.018	.009	.006	.011
		R	.945 - .970	.689 - .694	.466 - .470	.208 - .233	.050 - .063	.073 - .082	.162 - .178

Table 2, Continued. Morphometric ratios for larval American shad, Alosa sapidissima (Wilson): Based on Notochord-Standard Length

Size Interval	N	STAT	SL/TL	PAL/SL	PDL/SL	HL/SL	SNTL/SL	ED/SL	BD/SL
		$\bar{X}$	.953	.649	.493	.243	.058	.076	.175
24.00 - 24.99	1	SD	-	-	-	-	-	-	-
		R	-	-	-	-	-	-	-
		$\bar{X}$	.945	.626	.425	.243	.060	.090	.209
25.00 - 25.99	3	SD	.020	.030	.011	.002	.007	.005	.012
		R	.930 - .971	.592 - .650	.415 - .437	.241 - .244	.054 - .068	.084 - .093	.199 - .223
		$\bar{X}$	.952	.658	.461	.262	.071	.092	.209
27.00 - 27.99	1	SD	-	-	-	-	-	-	-
		R	-	-	-	-	-	-	-
		$\bar{X}$	.939	.654	.473	.254	.067	.075	.203
28.00 - 28.99	3	SD	.003	.012	.001	.007	.004	.002	.022
		R	.937 - .942	.641 - .664	.473 - .474	.249 - .262	.065 - .071	.073 - .077	.181 - .225
		$\bar{X}$	.954	.659	.434	.235	.055	.066	.194
29.00 - 29.99	2	SD	.002	.002	.008	.010	.003	.008	.002
		R	.952 - .955	.658 - .660	.429 - .438	.228 - .242	.053 - .058	.060 - .072	.192 - .195
		$\bar{X}$	.953	.661	.437	.225	.054	.072	.193
30.00 - 30.99	1	SD	-	-	-	-	-	-	-
		R	-	-	-	-	-	-	-
		$\bar{X}$	.949	.659	.436	.275	.064	.089	.215
31.00 - 31.99	1	SD	-	-	-	-	-	-	-
		R	-	-	-	-	-	-	-

$\bar{X}$ = Mean; SD = Standard Deviation; R = Range; * = Only One Value; ** = Missing Values; TL = Total Length; SL = Standard Length; PAL = Preanal Length; PDL = Predorsal Length; HL = Head Length; SNTL = Snout Length; ED = Horizontal Eye Diameter; BD = Body Depth

Table 3. Distribution of myomeres relative to other body morphology for *Alosa sapidissima* (Wilson) larvae.

Size Interval (mm SL)	Preanal Myomeres			Postanal Myomeres			Predorsal Myomeres		
	N	$\bar{X}$	R	N	$\bar{X}$	R	N	$\bar{X}$	R
8.0 to *9.0	11	48.4	45 - 52	9	12.3	10 - 14	11	33.9	31 - 36
9.1 to 12.0	18	46.1	43 - 51	17	11.6	10 - 14	18	30.7	28 - 35
12.1 to 15.0	9	44.4	42 - 48	7	14.6	11 - 16	9	28.5	26 - 33
15.1 to 18.0	7	41.3	39 - 43	7	15.6	13 - 17	7	23.3	21 - 26
18.1 to 21.0	3	39.0	36 - 42	-	-	-	3	22.6	21 - 24
21.1 to 24.0	4	38.5	35 - 43	-	-	-	4	21.0	20 - 23

N = Number of specimens counted

$\bar{X}$ = Mean of myomere counts

R = Range of myomeres in that size interval

* In the 8.0 to 9.0 size interval, the specimens used were from the 1978 culture at USFWS Harrison Lake National Fish Hatchery (Mr. Alan Blair, Manager).

Table 4. Some fin meristics for larval Alosa sapidissima (Wilson) cultured at USFWS Harrison Lake National Fish Hatchery

	Notochord-Standard Length (mm)	Dorsal Rays	Anal Rays	Pectoral Rays	Pelvic Rays	Caudal Rays			
						Superior Procurrent Rays	Superior Principle Rays	Inferior Principle Rays	Inferior Procurrent Rays
A	9.25	8	-	-	-	-	-	-	-
	9.59	7	-	-	-	-	-	-	-
	9.91	8	-	-	-	-	-	-	-
	10.00	8	-	-	-	-	-	-	-
	10.40	9	-	-	-	-	-	-	-
	10.72	9	-	-	-	-	-	-	-
	10.85	10	-	-	-	-	-	-	-
	11.00	9	-	-	-	-	-	-	-
	11.17	9	-	-	-	-	-	-	-
	11.42	10	-	-	-	-	2	-	-
	11.81	12	3	-	-	-	2	-	-
B	12.12	12	-	-	-	1	2	2	2
	12.28	13	-	-	-	2	4	2	2
	12.50	13	8	-	-	4	7	4	-
	13.45	15	9	-	-	4	9	5	2
	13.50	14	-	-	-	3	9	3	3
	13.85	16	12	3	-	-	9	-	-
	15.44	17	15	-	-	-	10	4	4
	15.93	17	19	-	-	3	10	4	5
	15.94	16	8	-	-	-	10	-	-
	16.15	18	9	5	-	-	10	4	4
	16.17	17	-	2	-	-	10	4	4
	16.91	17	17	3	-	5	10	7	-
	17.77	18	15	-	-	7	10	5	5
C	19.33	18	20	-	4	7	10	7	6
	19.41	18	19	8	-	5	10	5	6
	19.47	18	18	10	-	8	10	9	7
	19.92	17	20	13	6	8	10	9	6
	21.66	18	21	-	-	7	10	9	7
	21.91	18	19	-	-	8	10	9	7
	23.13	19	19	11	-	8	10	9	7
	23.46	19	20	-	-	8	10	9	7
	24.61	19	22	15	-	8	10	9	7
	25.76	19	23	15	8	8	10	9	7
	26.52	19	22	16	7	8	10	9	6
	26.64	19	22	14	7	8	10	9	7
	26.67	19	21	16	8	8	10	9	7
	27.82	19	20	16	9	8	10	9	6
	28.51	19	19	16	9	8	10	9	7
	29.50	19	23	15	10	8	10	9	7

A = Preflexion Larvae
B = Flexion Larvae
C = Postflexion Larvae

Table 5. Fin development meristics for postflexion (juvenile) Alosa sapidissima (Wilson) [1, 2]

Standard Length (mm)	Dorsal Rays	Anal Rays	Pectoral Rays	Pelvic Rays	Caudal Rays			
					Superior Procurrent Rays	Superior Principle Rays	Inferior Principle Rays	Inferior Procurrent Rays
26.5	19	22	15	9	8	10	9	6
26.8	18	23	14	9	8	10	9	7
27.4	18	23	15	9	8	10	9	7
28.2	19	22	16	9	8	10	9	7
28.4	19	22	18	9	8	10	9	6
28.5	19	22	17	9	7	10	9	6
28.6	17	23	17	10	7	10	9	7
28.8	18	23	17	8	7	10	9	6
29.0	17	-	17	9	8	10	9	7
29.1	18	22	14	8	7	10	9	7
29.2	17	21	18	9	7	10	9	7
29.3	18	20	14	8	8	10	9	7
29.5	19	23	15	9	8	10	9	6
29.6	19	23	17	10	8	10	9	7
30.2	21	19	16	8	7	10	9	7
30.4	17	24	16	8	8	10	9	7
31.7	18	21	14	8	8	10	9	7
31.8	18	22	15	9	8	10	9	7
31.8	18	22	15	9	7	10	9	7
32.2	18	21	18	9	7	10	9	6
32.4	19	20	15	11	8	10	9	7
32.9	17	23	15	8	8	10	9	7
33.0	17	21	16	10	7	10	9	6
33.4	17	20	17	8	7	10	9	6
36.2	18	21	18	8	8	10	9	7
37.2	18	23	16	9	8	10	9	7
37.8	18	22	17	10	7	10	9	6
38.4	17	22	14	10	7	10	9	7

[1] Field sampled Alosa Sapidissima from juvenile nursery grounds on the Pamunkey River, Virginia (Figure 1).

[2] All field sampled specimens were in the postflexion stage of caudal development.

Table 6. Summary of fin development sequence in larvae of Alosa sapidissima (Wilson)

Fin	Standard Length [1,2]			Number Rays in Fully Developed Fins
	Buds First Appear[3]	Rays First Appear	Full Complement of Rays	
Dorsal	8.0 to 9.0	9.0 to 9.3	17.0 to 20.0	17 to 20
Anal	11.0 to 11.7	11.8 to 12.5	19.0 to 21.0	19 to 23
Pectoral	*	13.8 to 19.4	23.8 to 25.7	14 to 18
Pelvic	17.0 to 19.0	19.0 to 20.0	25.0 to 27.0	8 to 10
Caudal				
Superior Procurrent		12.0 to 12.5	19.0 to 20.0	7 to 8
Superior Principle		11.0 to 12.0	15.0 to 15.5	10
Inferior Principle		12.0 to 12.5	19.0 to 19.5	9
Inferior Procurrent	-	12.0 to 12.5	19.0 to 20.0	6 to 7

[1] Rays were present but not necessarily ossified

[2] Rays were stained blue or red in order to be counted. (Blue = cartilaginous; Red = ossified bone)

[3] Includes the radial and basipterygium bones.

* Incipient rays are evident in yolksac larvae, but do not stain with alcian-blue or alizarin-red-s.

Table 7. Comparative meristics from several studies on larval, juvenile, and adult Alosa sapidissima (Wilson).

Author	Chambers et al. 1976			Jones et al. 1978			Lippson and Moran 1974			Mansueti and Hardy 1967			Nichols 1966			Hildebrand and Schroeder 1928			Leim 1924			Hildebrand 1963		
Development Stage	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Dorsal Fin Rays						14-21			14-20			16-17			17-20			17-19			15-19			17-20
Anal Fin Rays						18-25			18-25			21-22			19-23			19-23			18-24			20-23
Pectoral Fin Rays						3-15*			13-18			3-15*			15-18						14-18			15-17
Pelvic Fin Rays						5-7*			8-10			5-7*									8-10			
Preanal Myomeres																								
9.0-11.9 mm	45-50			44-50			41-47			43-47									43-47					
12.0-14.9 mm		45-52			45-49						41-45									41-45				
15.0-17.9 mm		46-51			44-52						37-44									37-44				
18.0-22.9 mm						32-47						34-42									35-41			
23 + mm																								

A = Preflexion
B = Flexion
C = Postflexion (includes juveniles to adults)
* = Development incomplete

Figure 1. Map of Pamunkey and Mattaponi Rivers, Virginia, indicating sampling locations for spawning adults and juvenile Alosa sapidissima (Wilson)

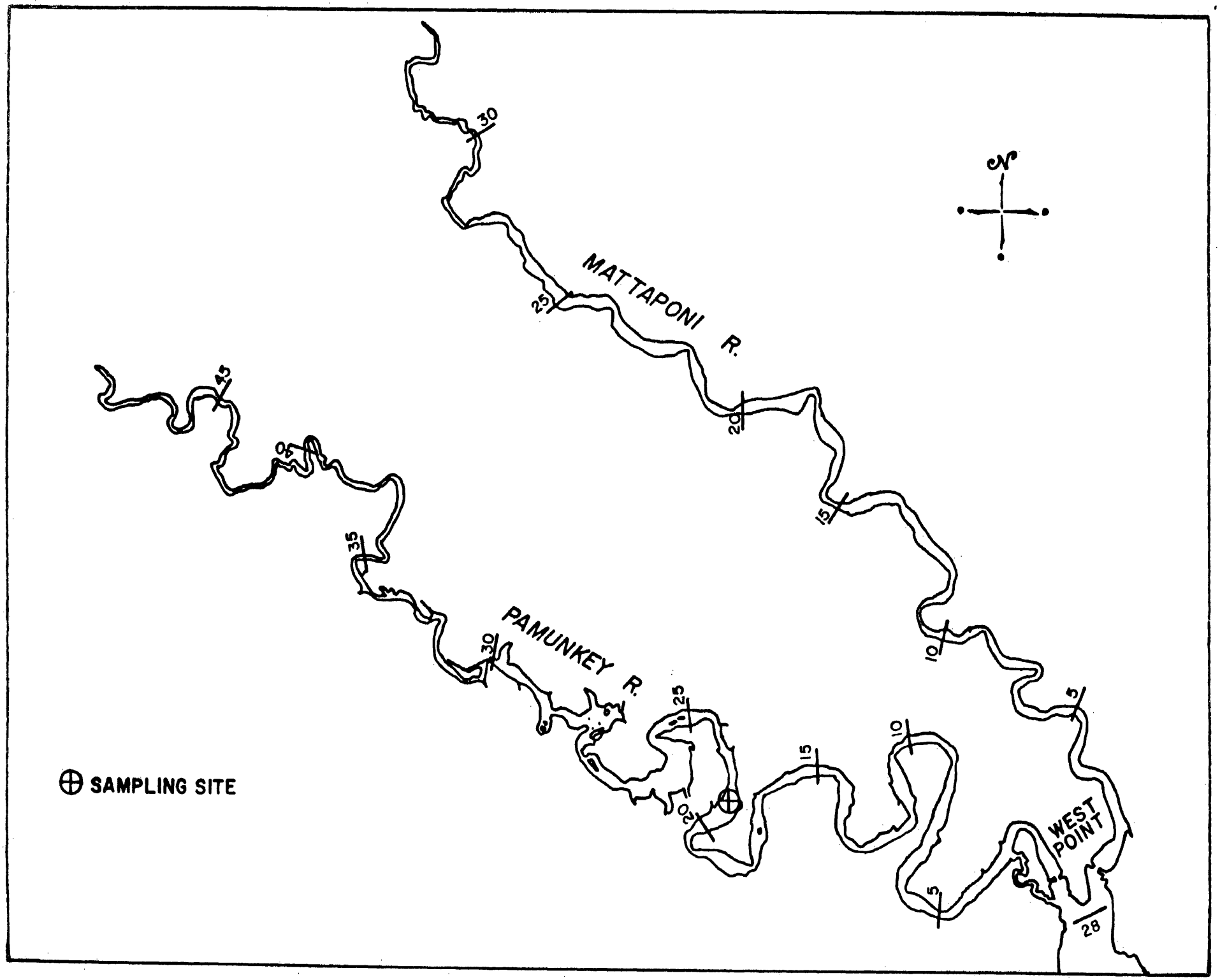

MATTAPONI R.
PAMUNKEY R.
WEST POINT
30
25
20
15
10
5
45
35
30
25
15
10
5
20
28
⊕ SAMPLING SITE

Figure 2. Egg hatching and larval collection apparatus used for American Shad, Alosa sapidissima (Wilson). Designed by Alan Blair, Manager, Harrison Lake National Fish Hatchery, Charles City, Virginia, in 1976

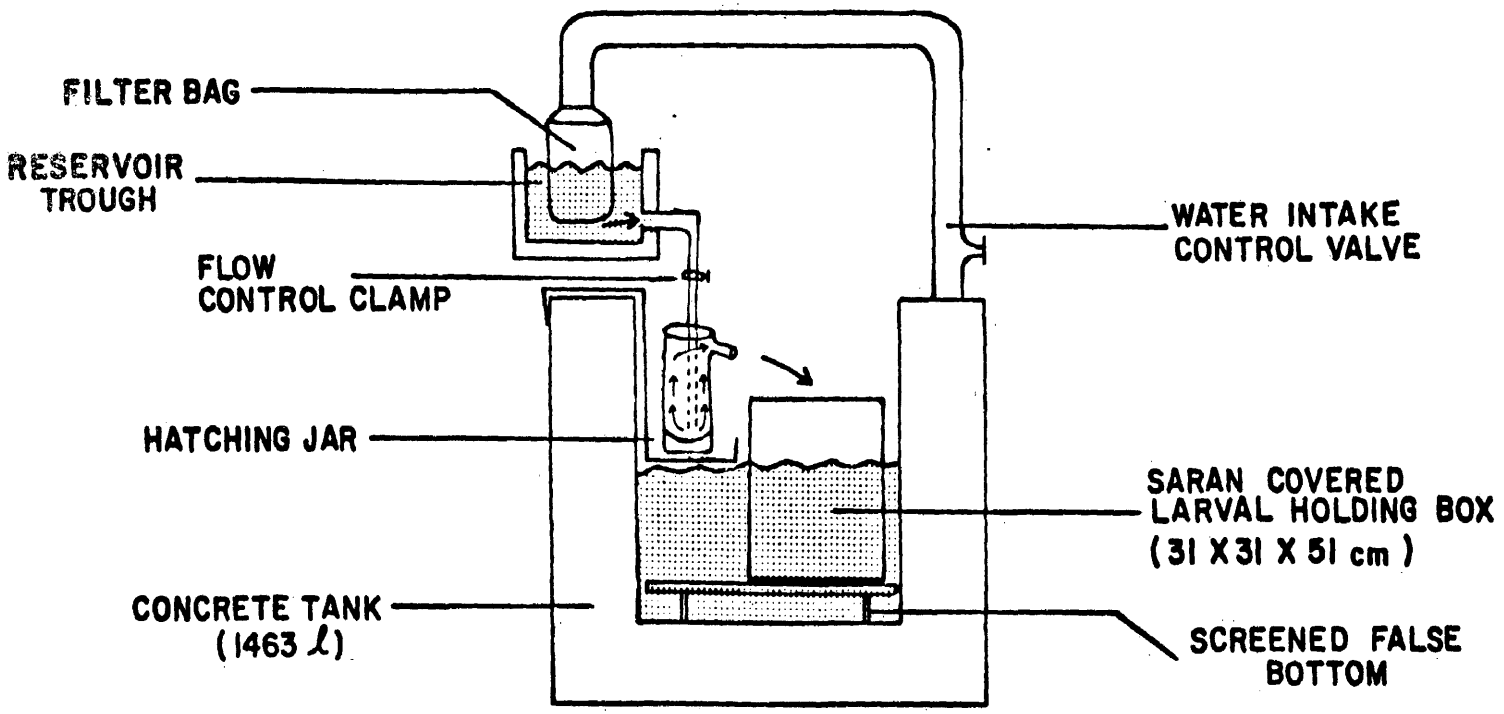

FILTER BAG
RESERVOIR TROUGH
FLOW CONTROL CLAMP
HATCHING JAR
CONCRETE TANK (1463 ℓ)
WATER INTAKE CONTROL VALVE
SARAN COVERED LARVAL HOLDING BOX (31 X 31 X 51 cm)
SCREENED FALSE BOTTOM

Figure 3. Screened raceway trough used for developing yolksac and larval *Alosa sapidissima*

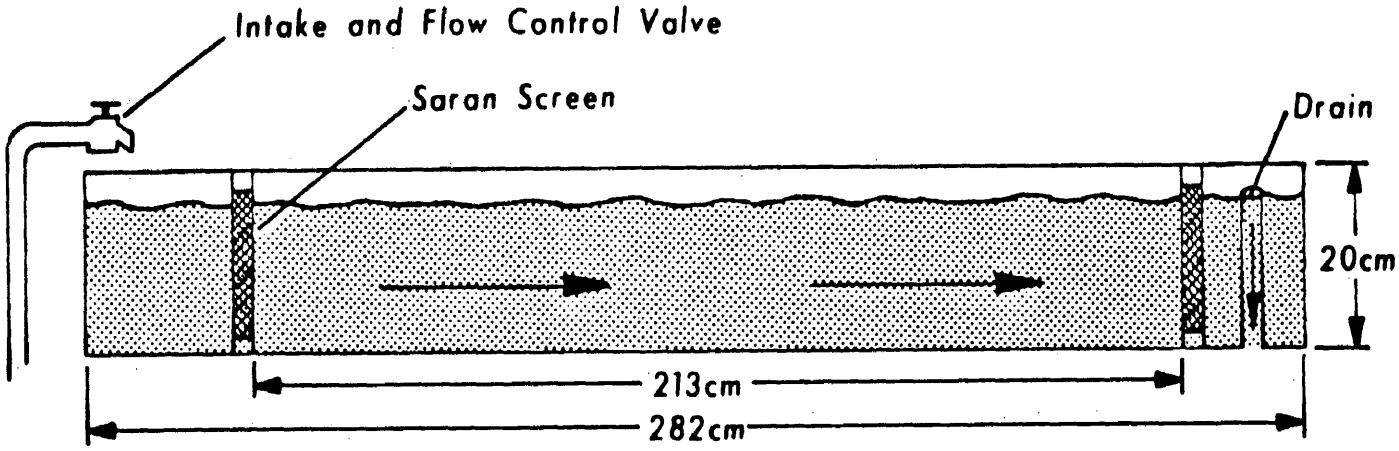

Intake and Flow Control Valve
Saran Screen
Drain
20cm
213cm
282cm

Figure 4. Scatterplot of total length (TL) versus notochord-standard length (SL) for larval Alosa sapidissima (Wilson). The regression equation is:

$TL = - .302 + 1.06\ SL : r^2 = .998$

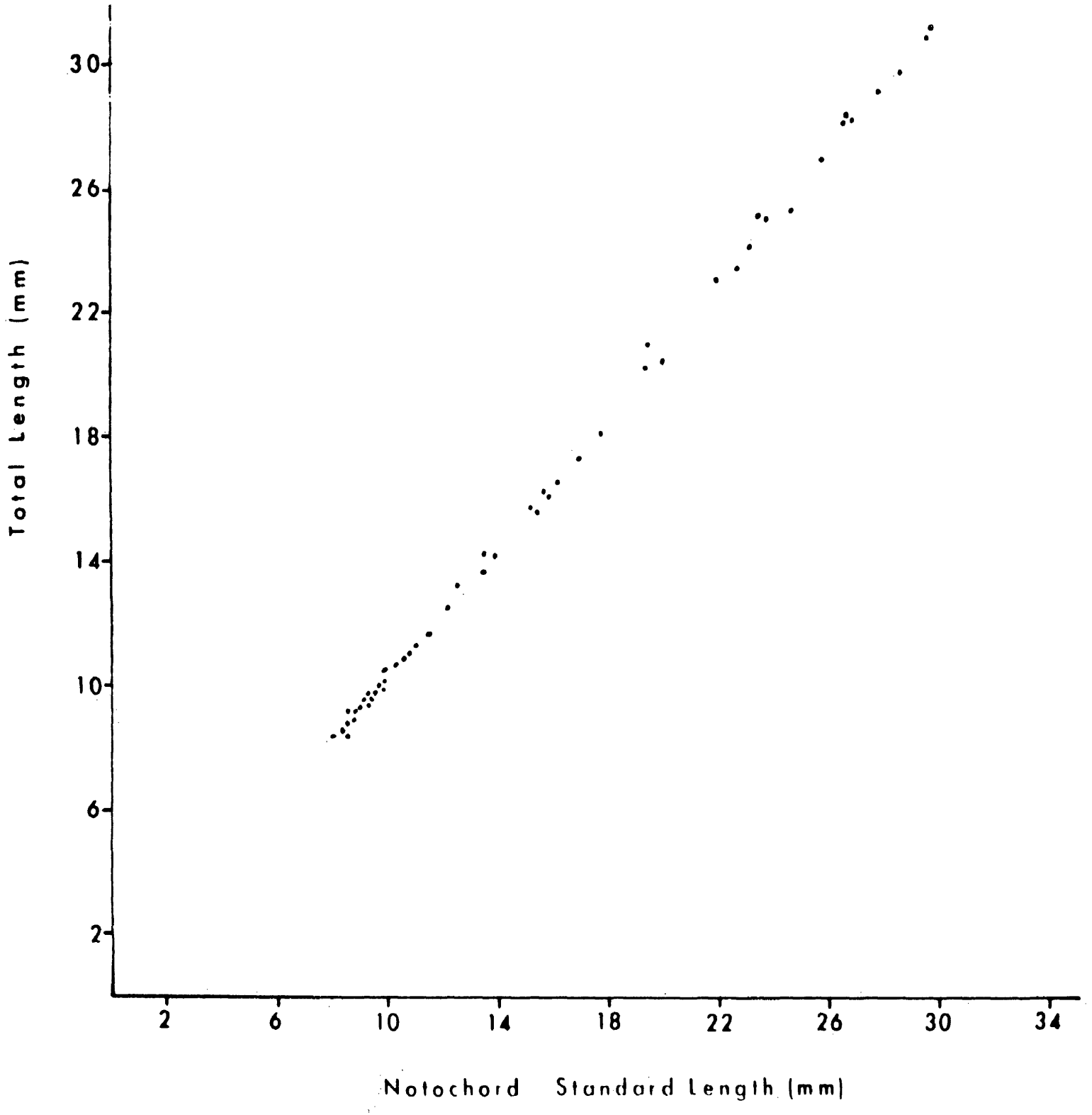

Total Length (mm)
30
26
22
18
14
10
6
2
2
6
10
14
18
22
26
30
34
Notochord Standard Length (mm)

Figure 5. Scatterplot of preanal length (PAL) versus notochord-standard length (SL) for larval Alosa sapidissima (Wilson). The regression equation is:

$$PAL = 2.18 + 0.60\ SL : r^2 = .969$$

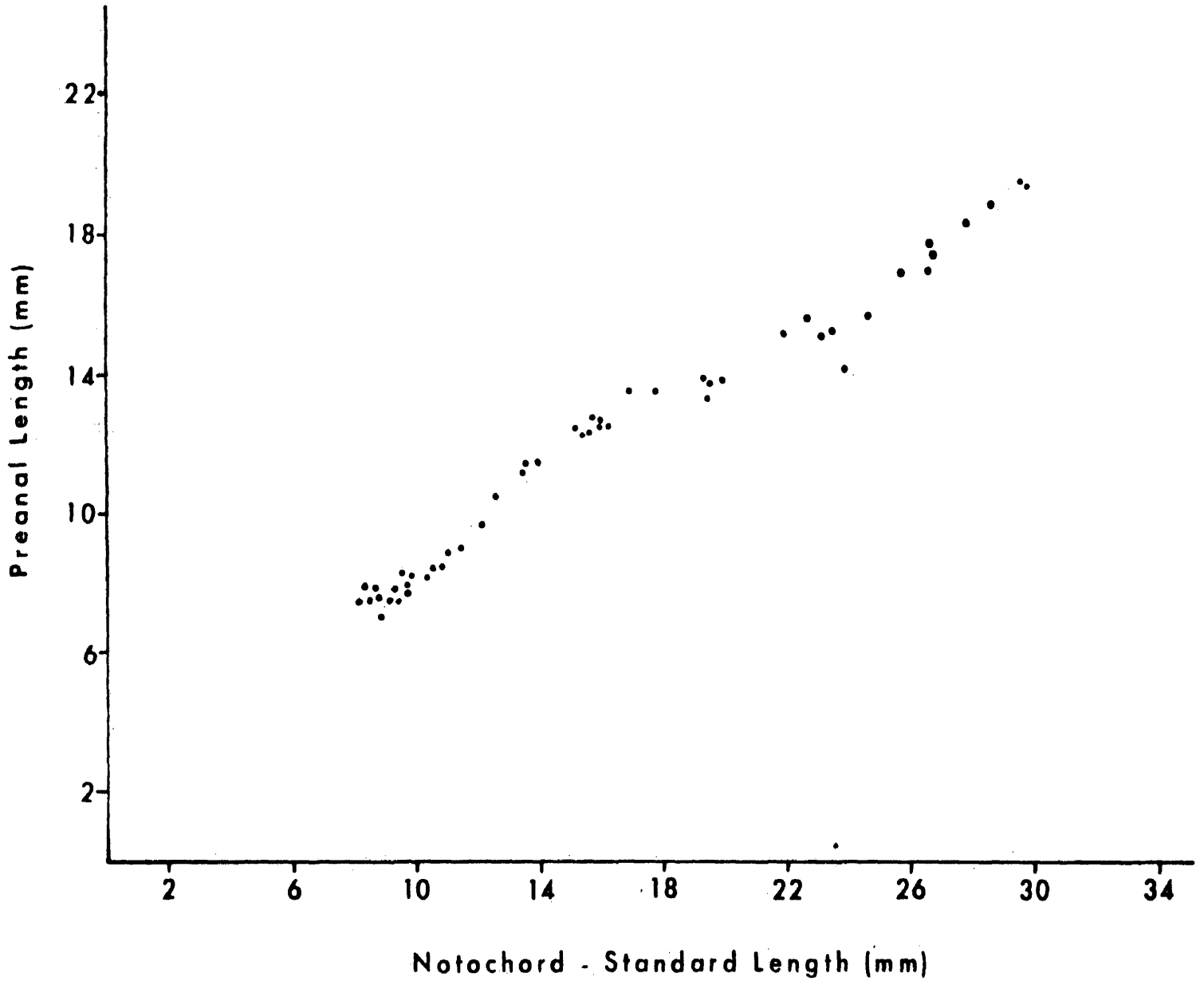

Preanal Length (mm)
22
18
14
10
6
2
2
6
10
14
18
22
26
30
34
Notochord - Standard Length (mm)

Figure 6. Scatterplot of predorsal length (PDL) versus notochord-standard length (SL) for larval Alosa sapidissima (Wilson). The regression equation is:

$PDL = 2.62 + 0.39\ SL : r^2 = .964$

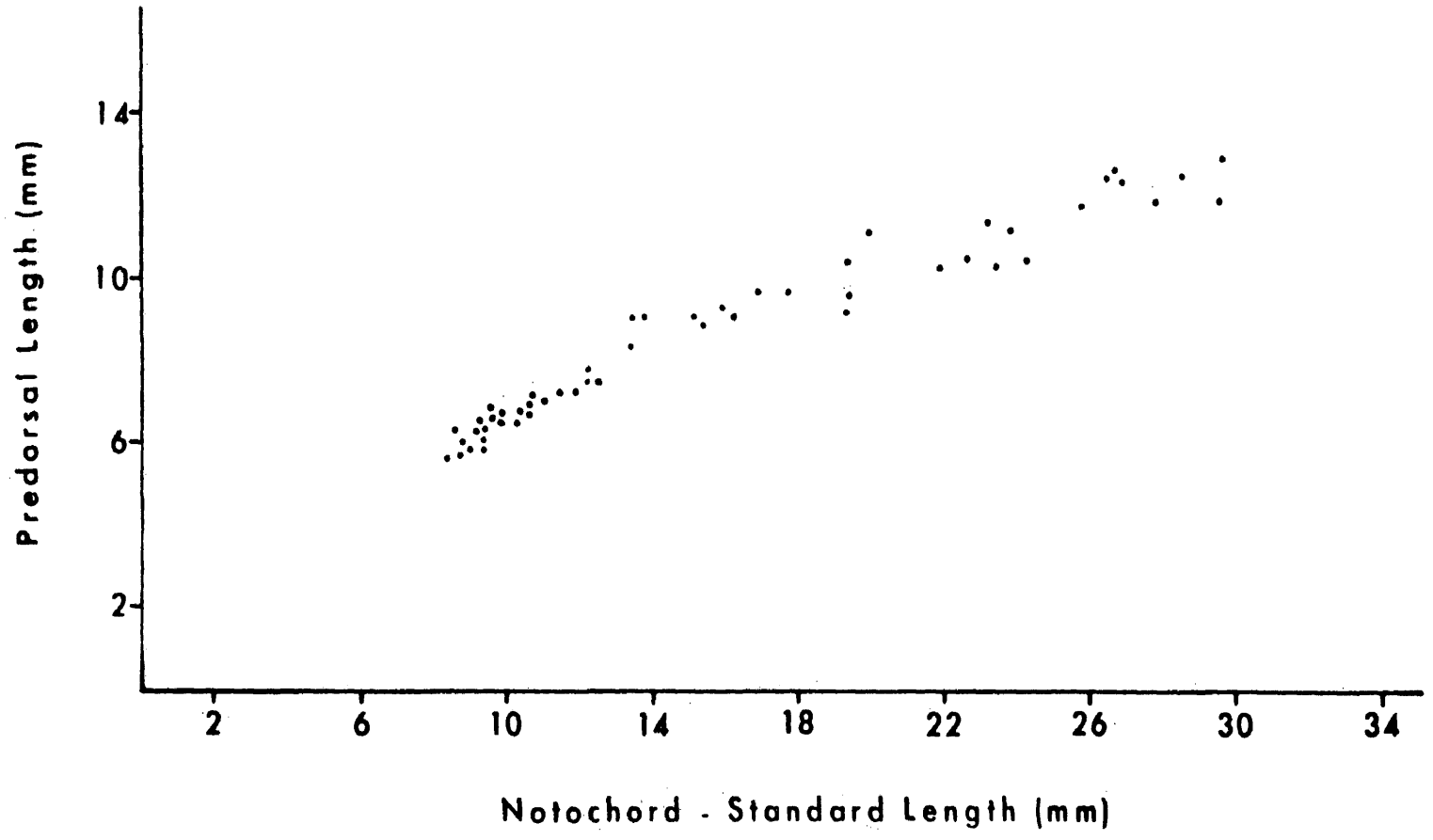

Predorsal Length (mm)
14
10
6
2
2
6
10
14
18
22
26
30
34
Notochord - Standard Length (mm)

Figure 7. Scatterplot of head length (HL) versus notochord-standard length (SL) for larval Alosa sapidissima (Wilson). The regression equation is:

$$\ln (HL) = \ln 0.05 + 1.50 \ln (SL) : r^2 = 0.992$$

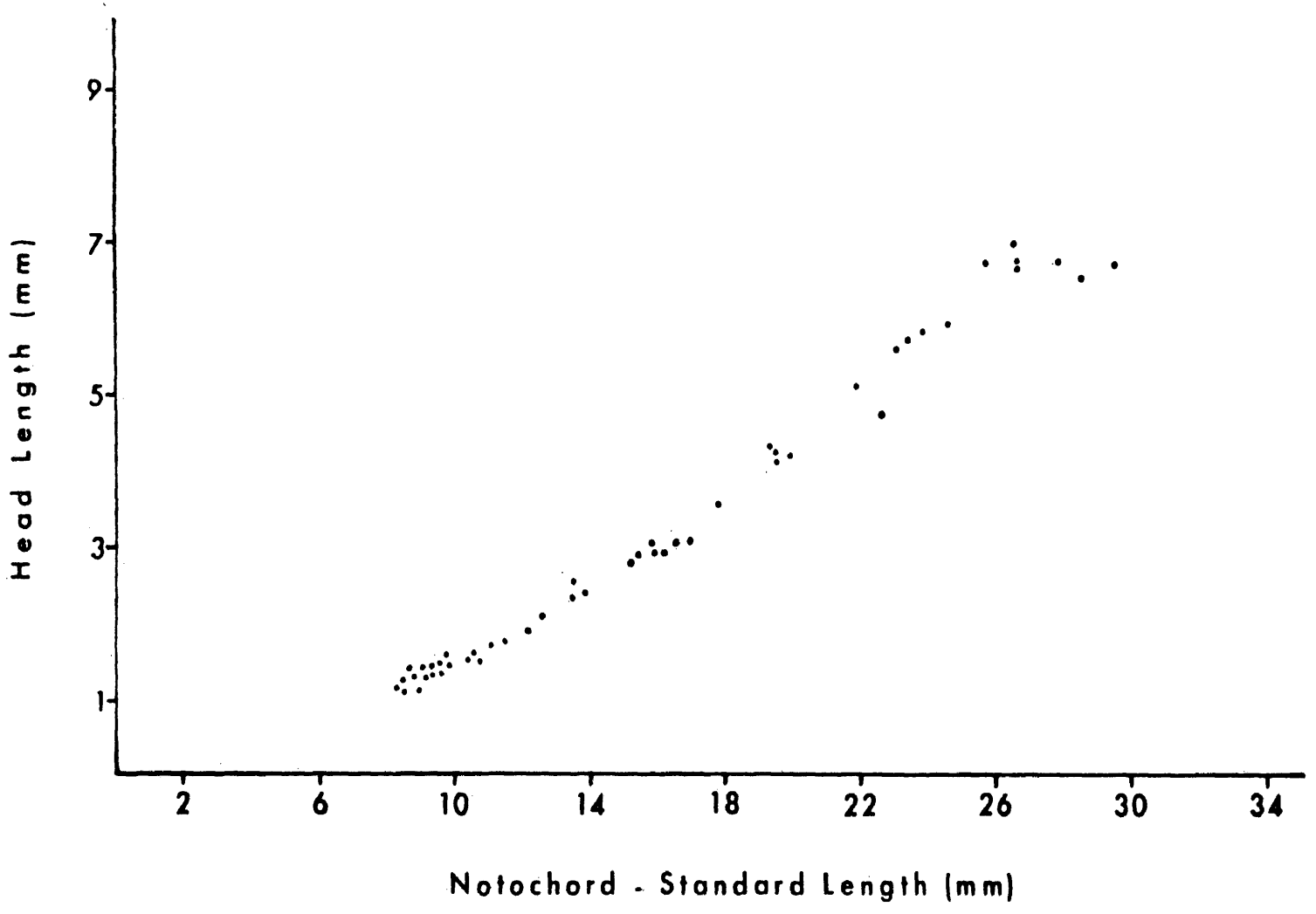

Head Length (mm)
9
7
5
3
1
2
6
10
14
18
22
26
30
34
Notochord - Standard Length (mm)

Figure 8. Scatterplot of horizontal eye diameter (HED) versus notochord-standard length (SL) for larval Alosa sapidissima (Wilson). The regression equation is:

$$\ln (HED) = \ln 0.01 + 1.59 \ln (SL) : r^2 = 0.973$$

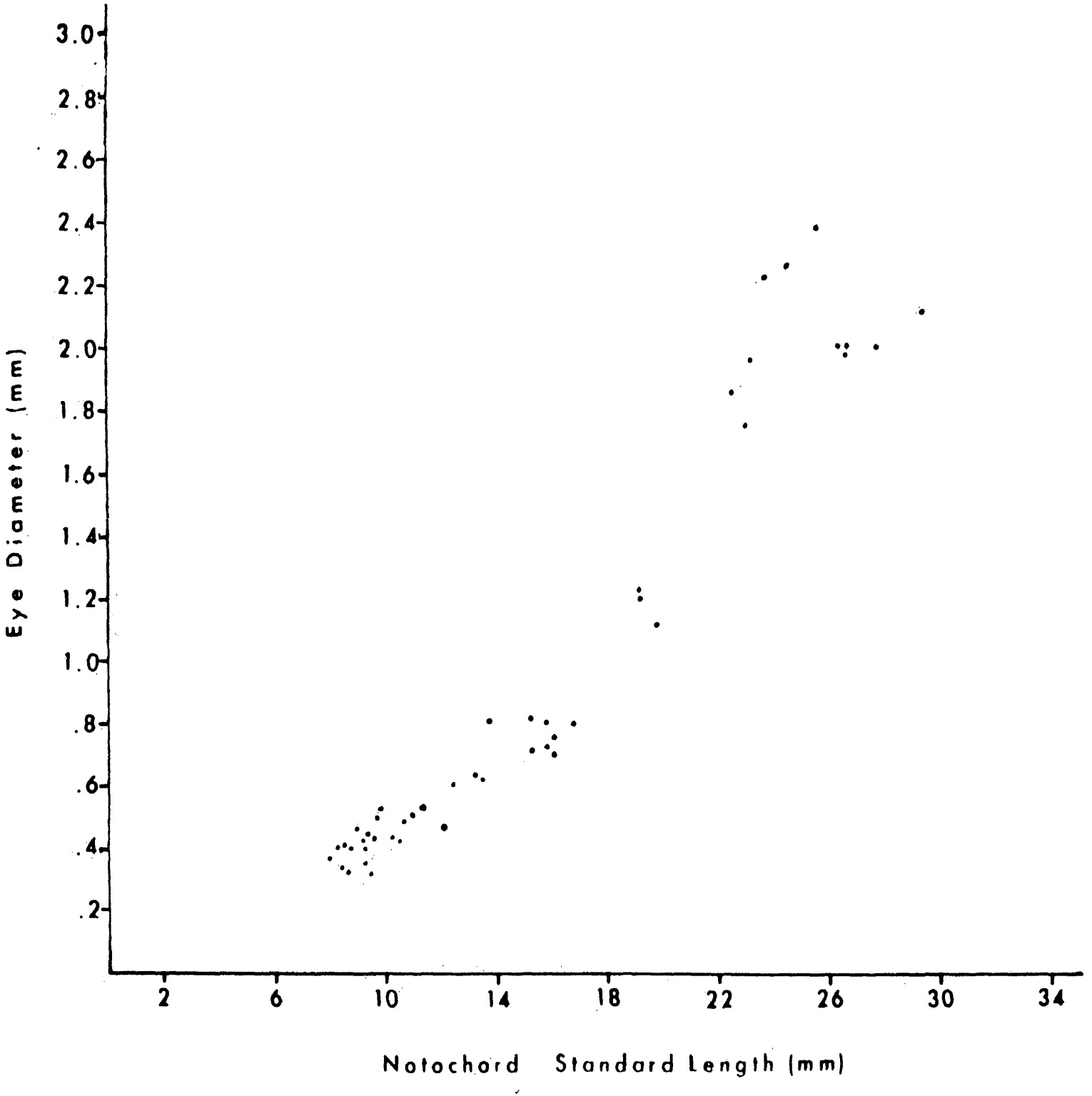

3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
Eye Diameter (mm)
2
6
10
14
18
22
26
30
34
Notochord Standard Length (mm)

Figure 9. Scatterplot of snout length (SNTL) versus notochord-standard length (SL) for larval Alosa sapidissima (Wilson). The regression equation is:

$$\ln (SNTL) = \ln 2.31 + 2.01 \ln (SL) : r^2 = 0.964$$

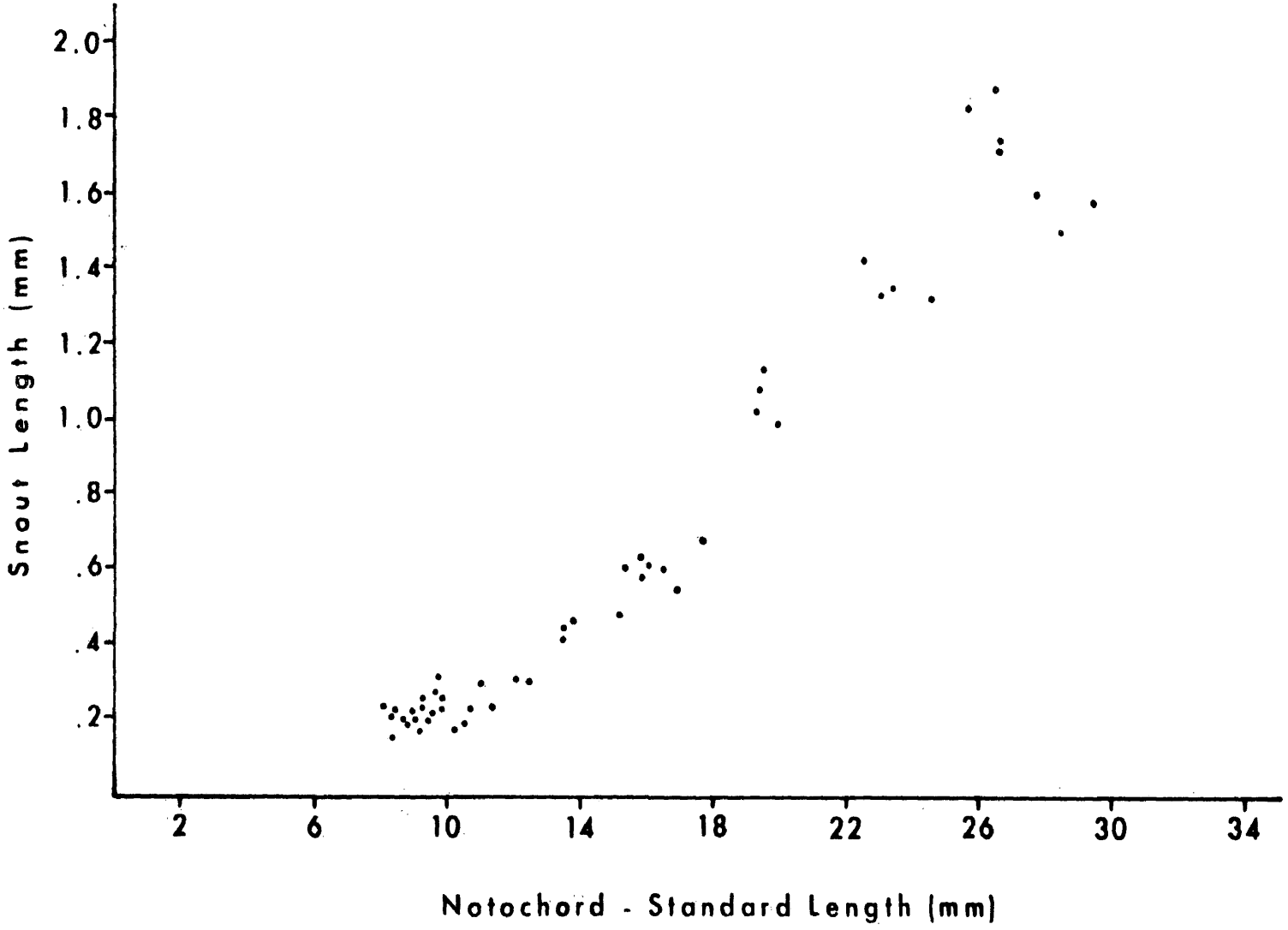

2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
Snout Length (mm)
2
6
10
14
18
22
26
30
34
Notochord - Standard Length (mm)

Figure 10. Scatterplot of body depth at first dorsal ray (BD) versus notochord-standard length (SL) for larval Alosa sapidissima (Wilson). The regression equation is:

$$\ln (BD) = \ln 4.91 + 2.14 \ln (SL) : r^2 = 0.977$$

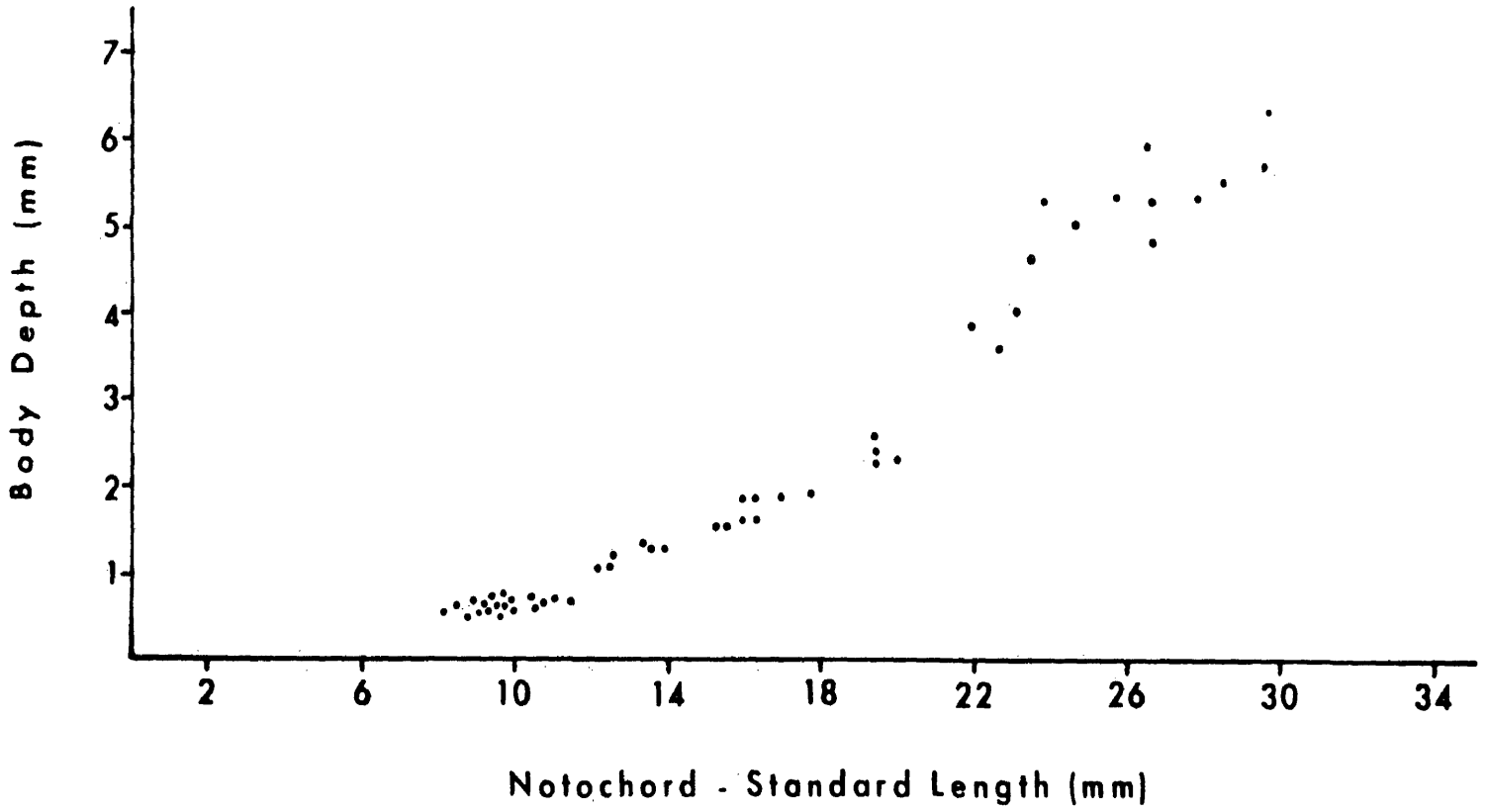

Body Depth (mm)
7
6
5
4
3
2
1
2
6
10
14
18
22
26
30
34
Notochord - Standard Length (mm)

Figure 11. Development of the caudal fin osteology in larval Alosa sapidissima (Wilson). Fin rays are omitted to clearly show support osteology: A, early preflexion, 9.2 mm; B, late preflexion, 10.8 mm; C, flexion, 13.2 mm; D, late flexion, 16.9 mm. Abbreviations: Hy_{1-6} = hypural plates, Ep = epurals, U_{1-2} = ural vertebrate, Pu_{1-2} = preural vertebrate, Hs = hemal spine, Nc = notochord, Ur_{1-2} = uroneurals, Ns = neural spine, Ph = parhypural, Na = neural arch. Clear areas indicate uptake of alizarin-red s (except in the notochord (N_c) in A, B, and C), while the stipled area indicates uptake of alcian-blue.

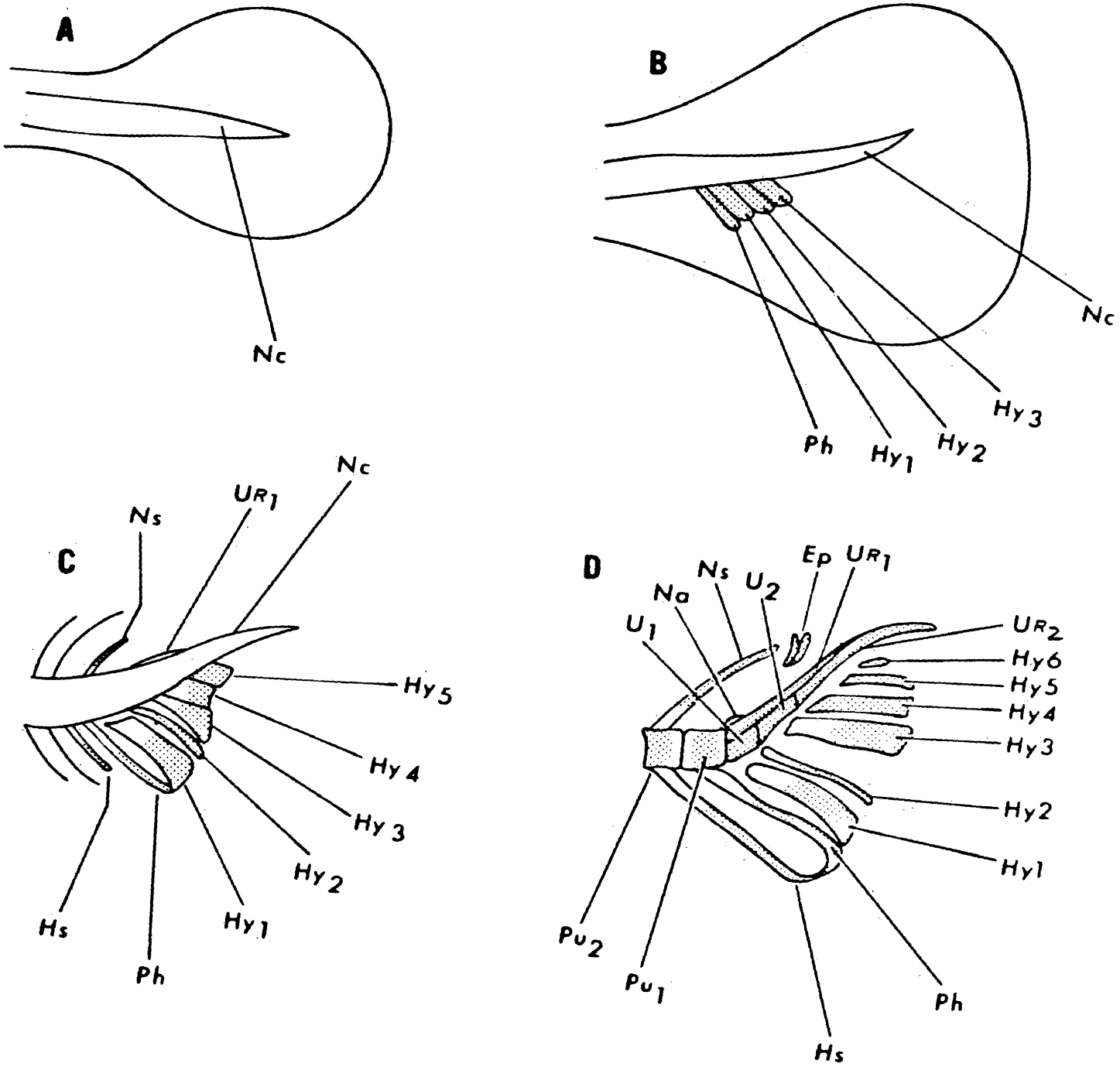

A
Nc
B
Nc
Hy3
Ph
Hy1
Hy2
C
Nc
Ns
UR1
Hy5
Hy4
Hy3
Hy2
Hs
Hy1
Ph
D
Ep
UR1
Ns
U2
Na
U1
UR2
Hy6
Hy5
Hy4
Hy3
Hy2
Hy1
Pu2
Pu1
Ph
Hs

Figure 12. Caudal fin osteology of a postflexion (juvenile) Alosa sapidissima (Wilson), 29.6 mm standard length. Abbreviations: Hy_{1-6} = hypural plates, Ep_{1-2} = epurals, U_{1-2} = ural vertebrate, Pu_{1-4} = preural vertebrate, Hs = hemal spine, Ur_{1-2} = uroneurals, Ns = neural spine, Ph = parhypural, Na = neural arch. Clear areas indicate uptake of alizarin-red s, while stipled areas indicate uptake of alcian-blue.

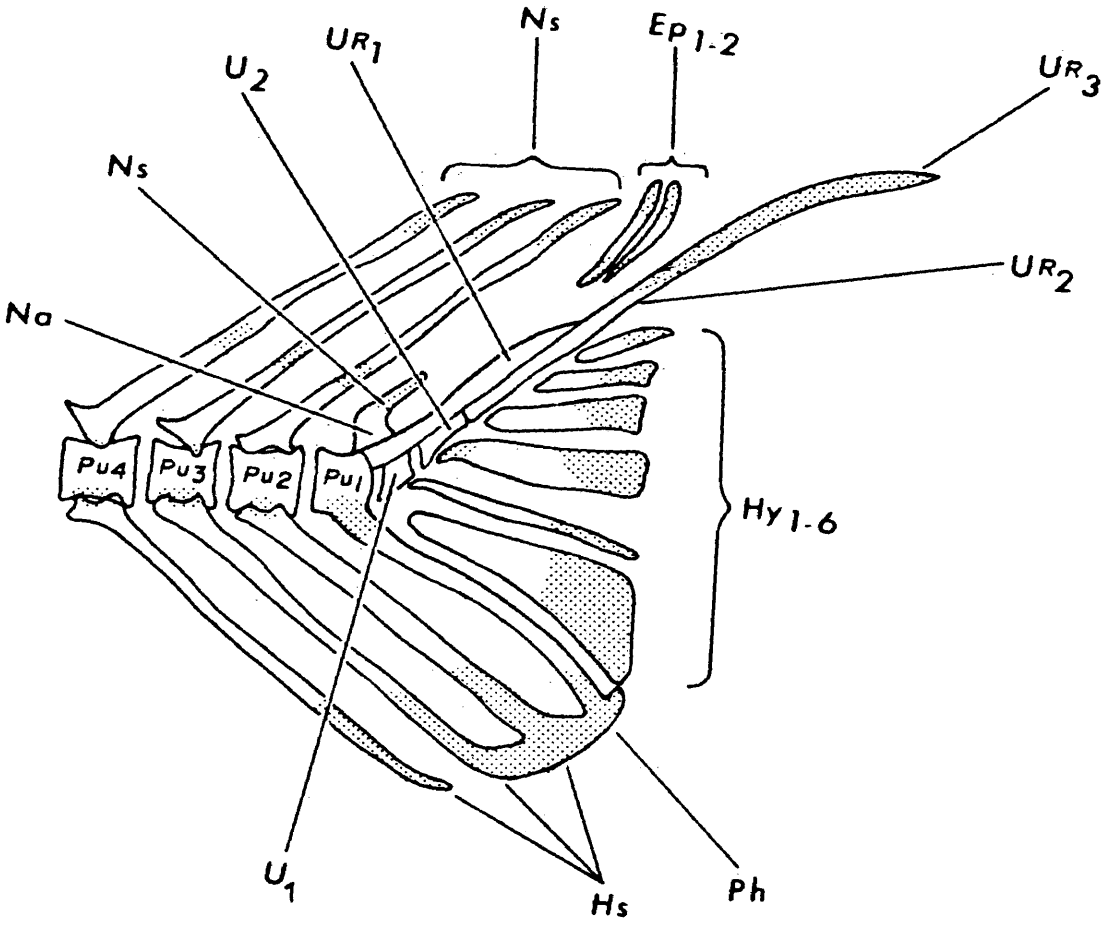

Ns
Ep 1-2
UR1
U2
UR3
Ns
UR2
Na
Pu4
Pu3
Pu2
Pu1
Hy 1-6
U1
Hs
Ph

Figure 13. *Alosa sapidissima* (Wilson), 9.3 mm preflexion yolksac larva.

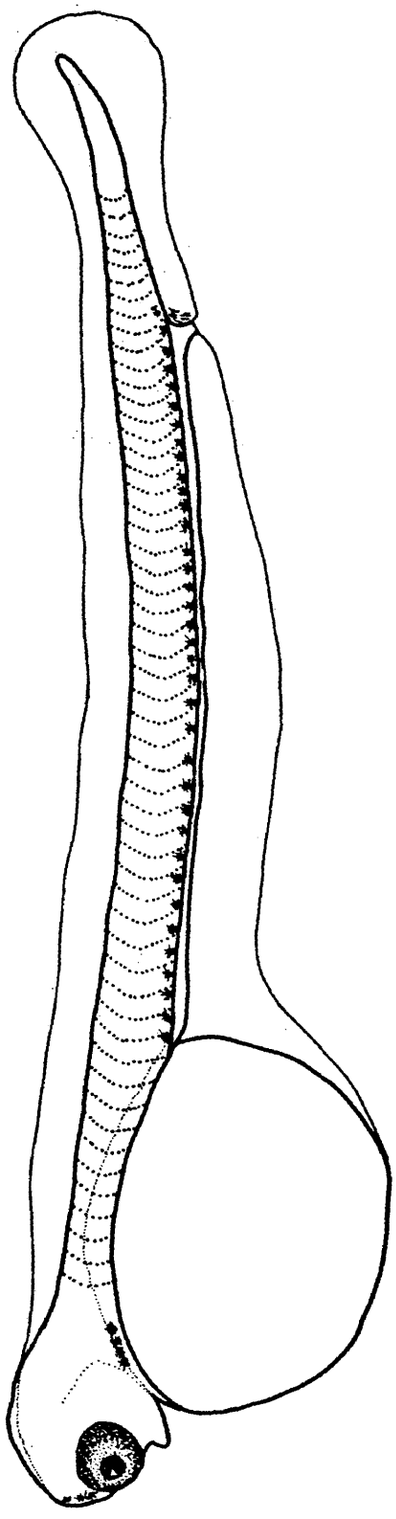


Figure 14. *Alosa sapidissima* (Wilson), 10.9 mm preflexion larva.

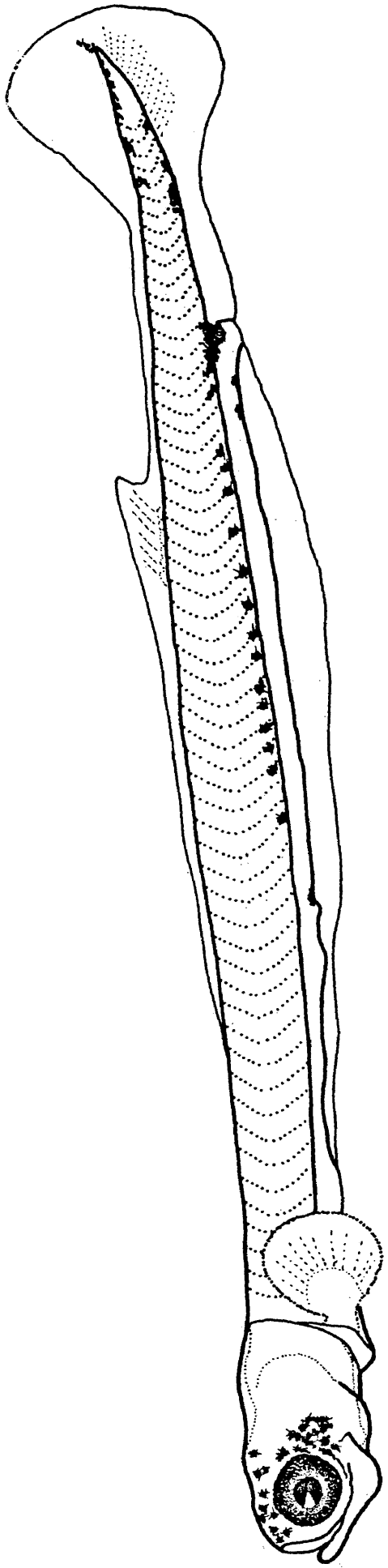


Figure 15. Alosa sapidissima (Wilson)
12.7 mm early flexion larva.

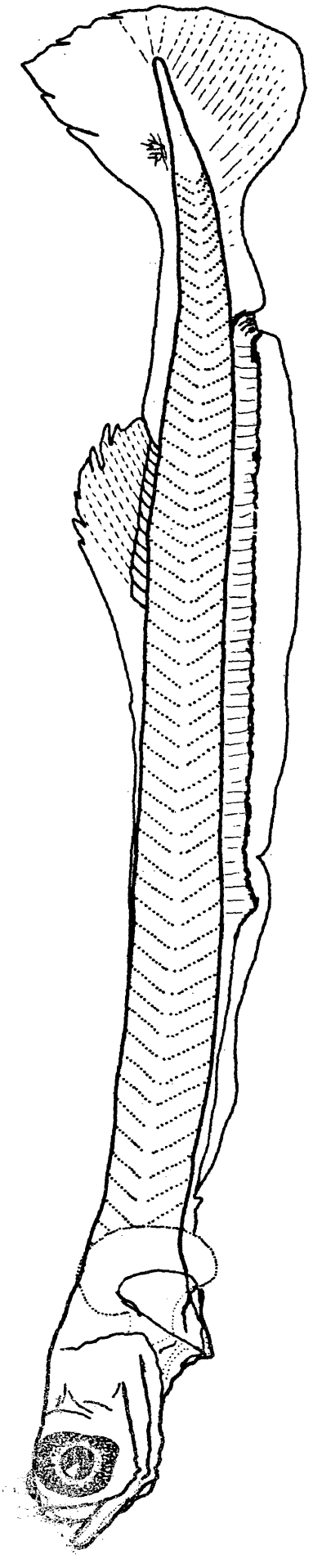


Figure 16. Alosa sapidissima (Wilson), 15.8 mm flexion larva.

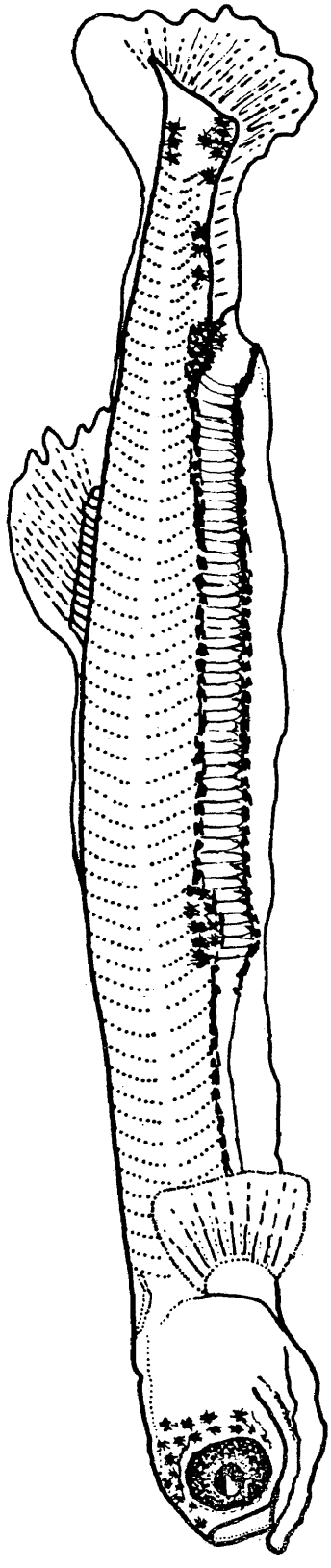


Figure 17. *Alosa sapidissima* (Wilson), 18.2 mm early postflexion larva.

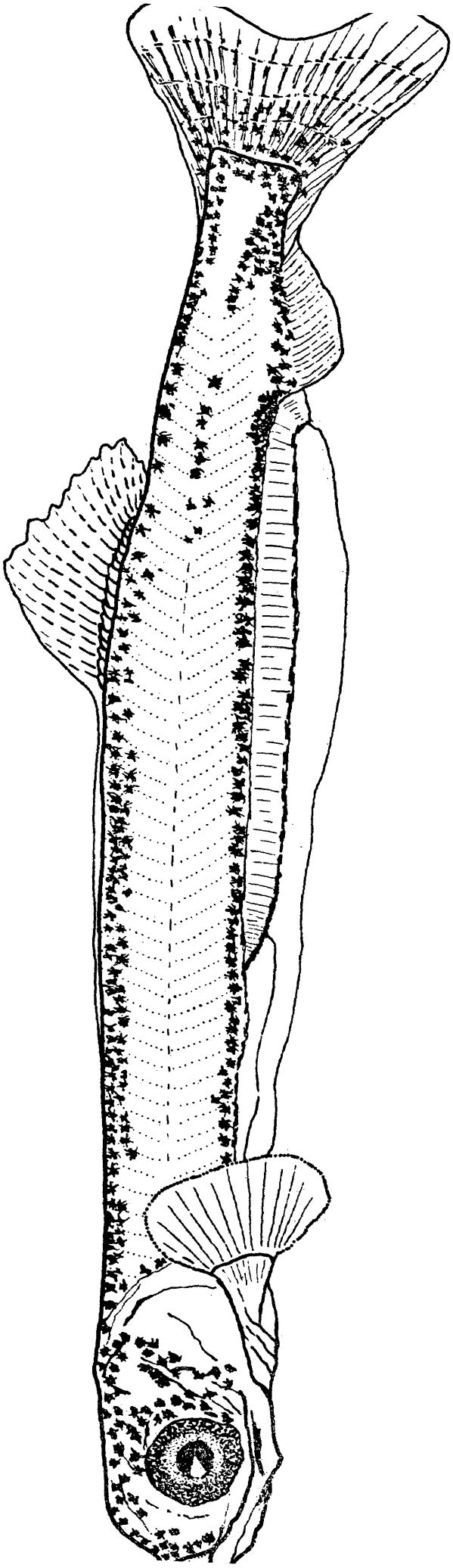


Figure 18. Alosa sapidissima (Wilson), 23.4 mm postflexion larva.

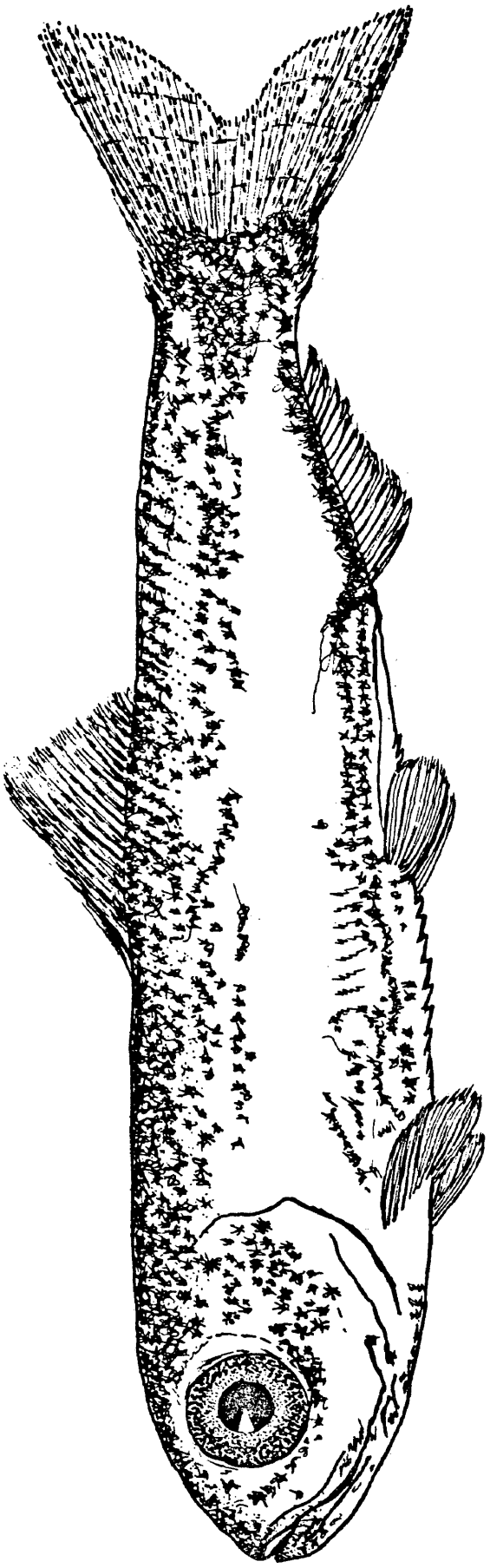


Figure 19. Alosa sapidissima (Wilson), 28.5 mm postflexion larva.

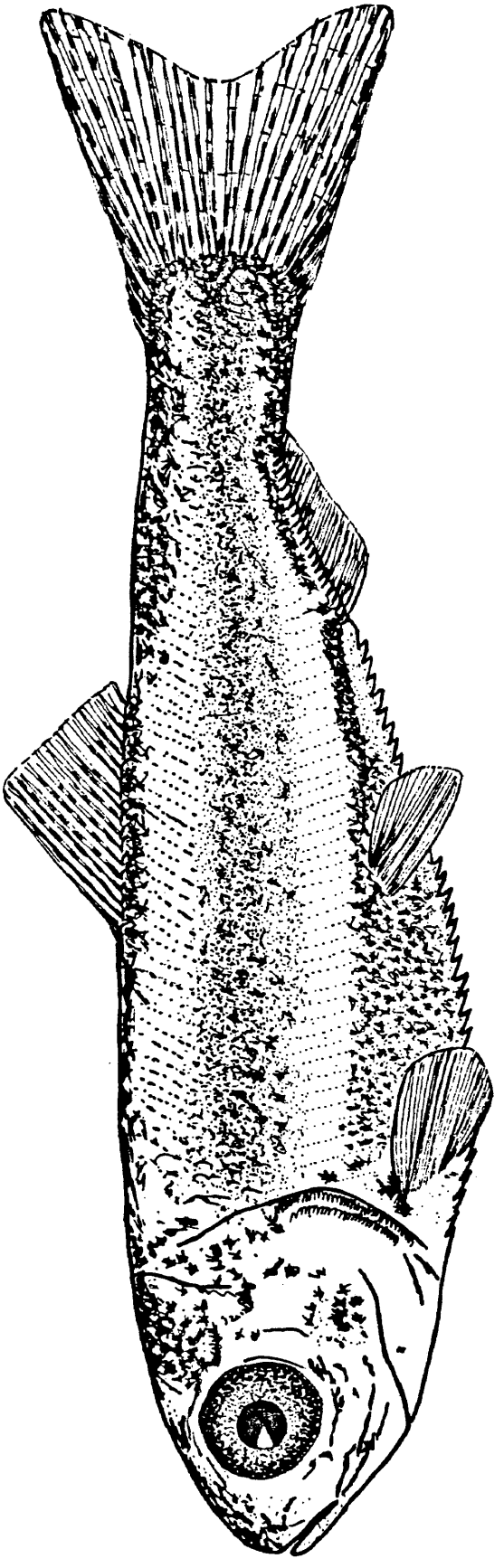


Figure 20. Scatterplot of preanal length (PAL) versus standard length (SL) measurements from cultured and wild postflexion Alosa sapidissima (Wilson).

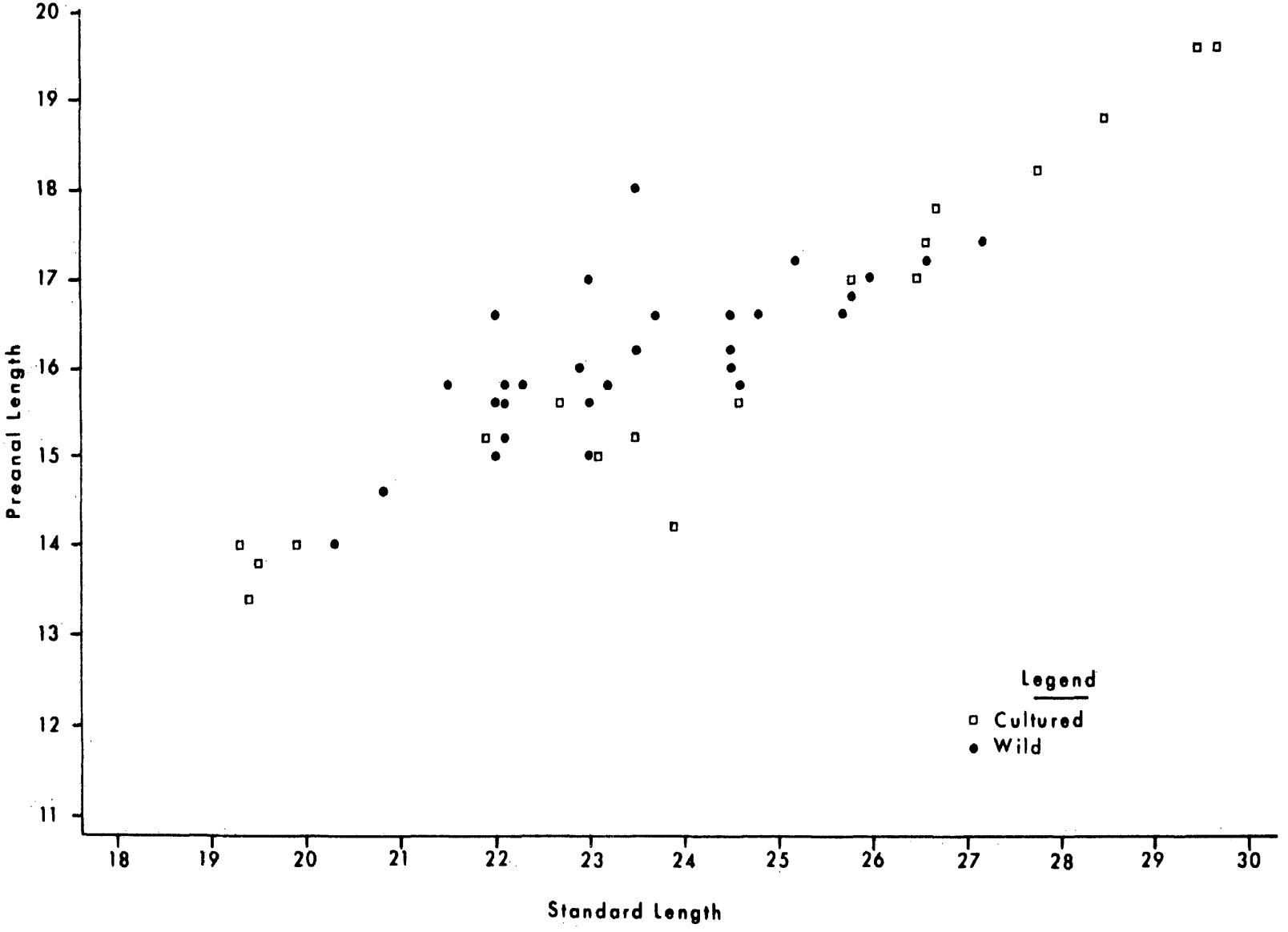

Preanal Length
Standard Length
Legend
Cultured
Wild
20
19
18
17
16
15
14
13
12
11
18
19
20
21
22
23
24
25
26
27
28
29
30

Figure 21. Scatterplot of predorsal length (PDL) versus standard length (SL) measurements from cultured and wild postflexion Alosa sapidissima (Wilson).

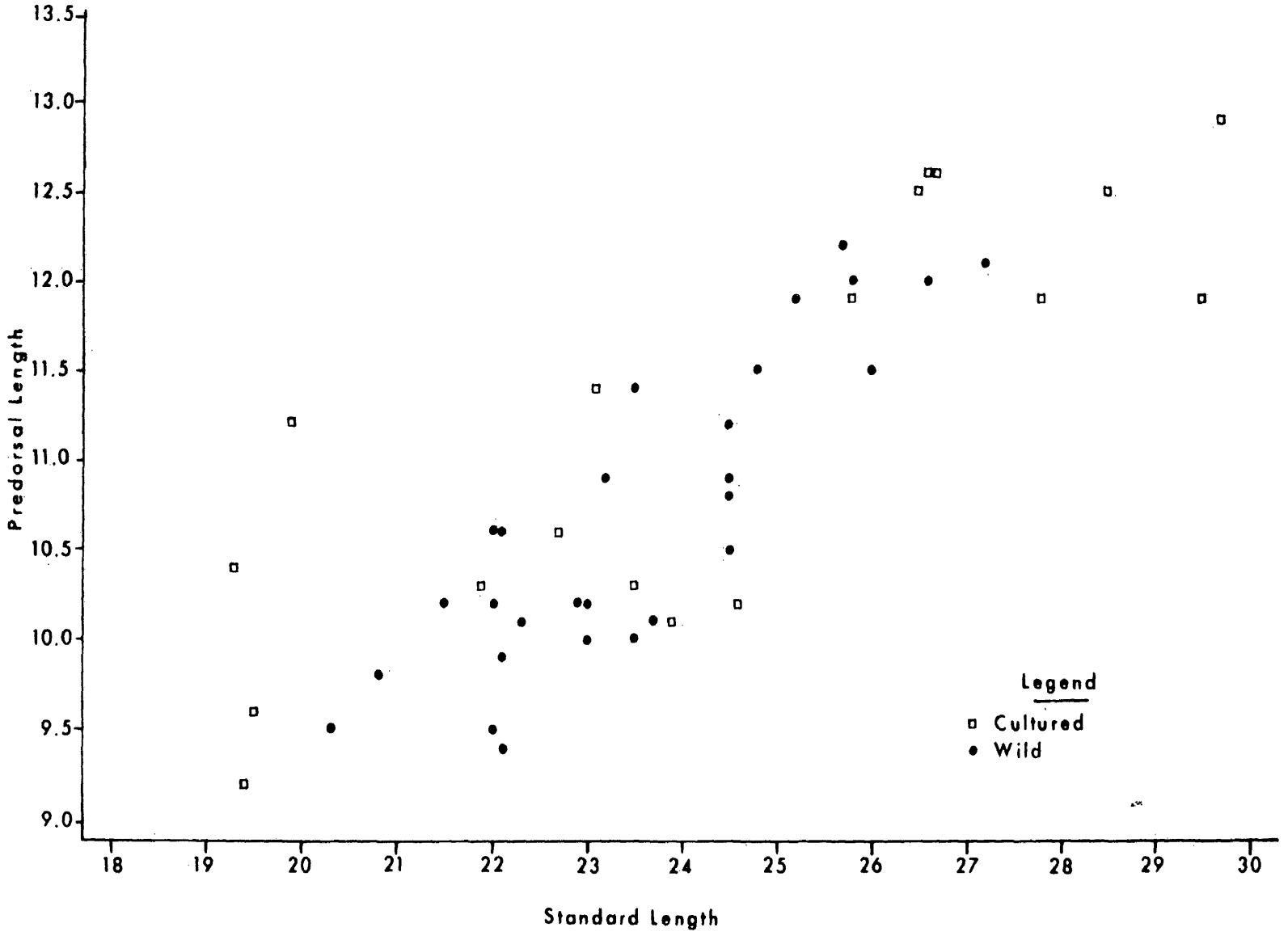

13.5
13.0
12.5
12.0
11.5
11.0
10.5
10.0
9.5
9.0
Predorsal Length
18
19
20
21
22
23
24
25
26
27
28
29
30
Standard Length
Legend
Cultured
Wild

Figure 22. Scatterplot of head length (HL) versus standard length (SL) measurements from cultured and wild postflexion Alosa sapidissima (Wilson).

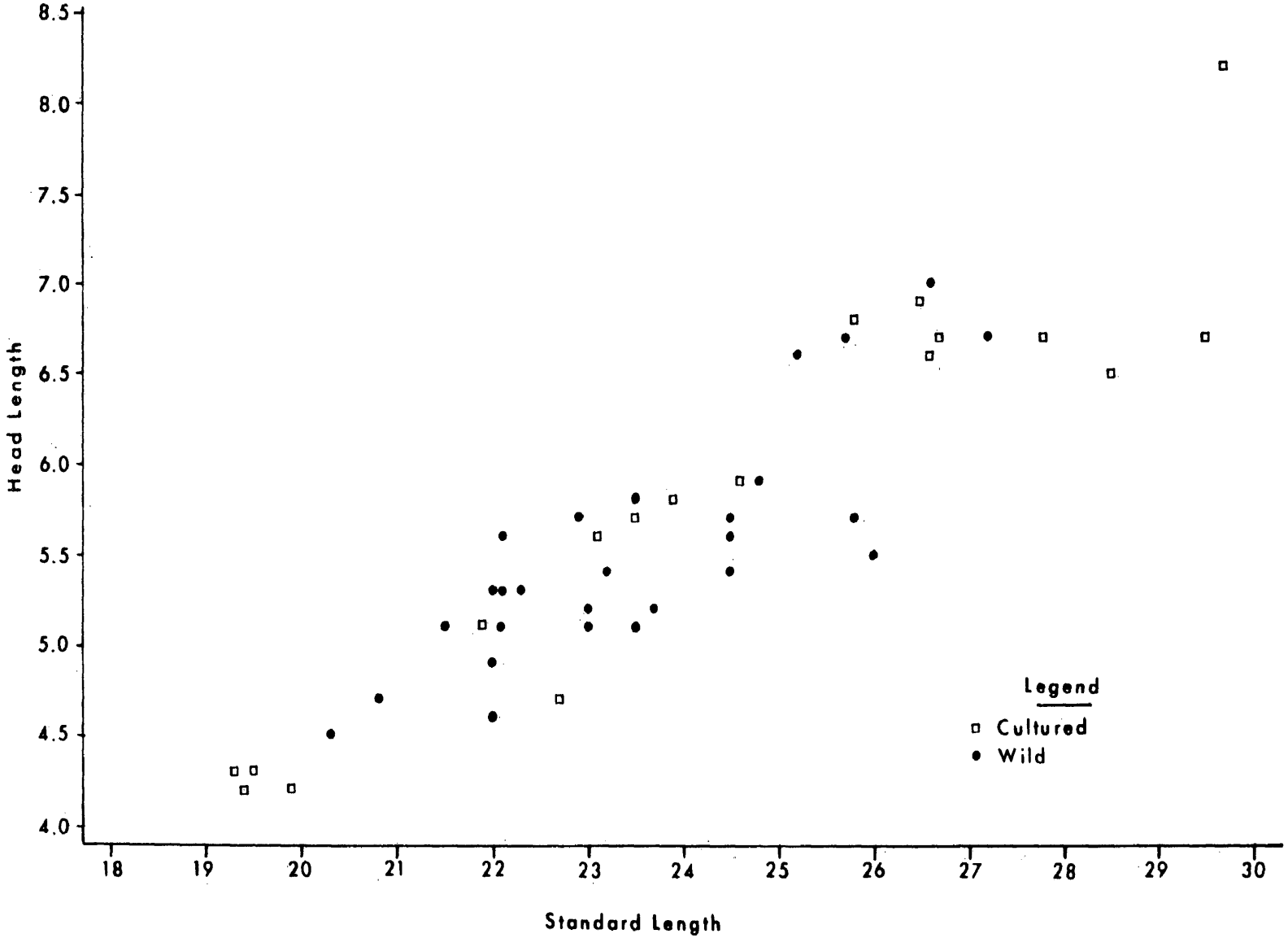

8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
Head Length
18
19
20
21
22
23
24
25
26
27
28
29
30
Standard Length
Legend
Cultured
Wild

Figure 23. Scatterplot of snout length (SNTL) versus standard length (SL) measurements from cultured and wild postflexion Alosa sapidissima (Wilson).

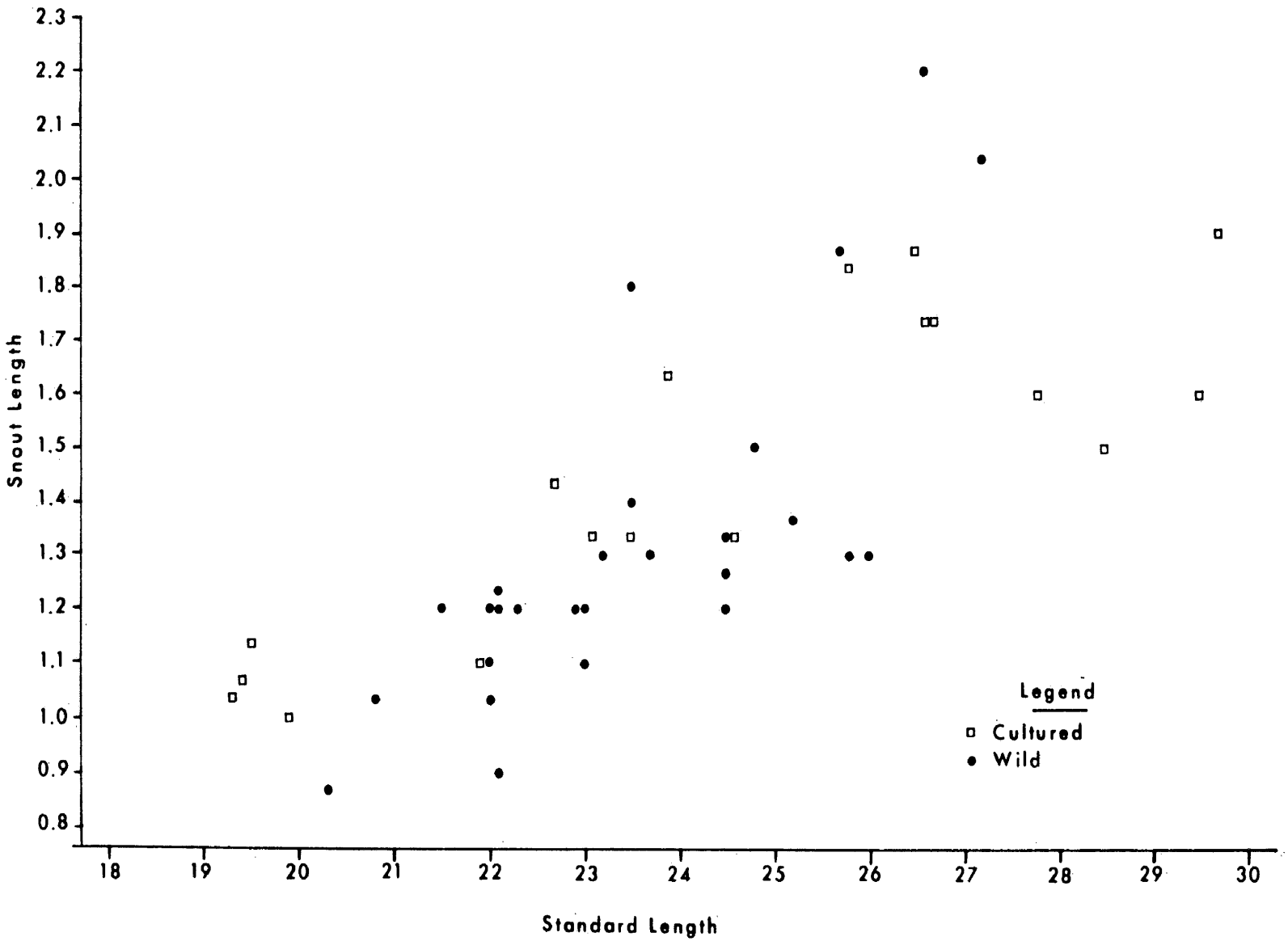

Snout Length
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
18
19
20
21
22
23
24
25
26
27
28
29
30
Standard Length
Legend
Cultured
Wild

Figure 24. Scatterplot of eye diameter (HED) versus standard length (SL) measurements from cultured and wild postflexion Alosa sapidissima (Wilson).

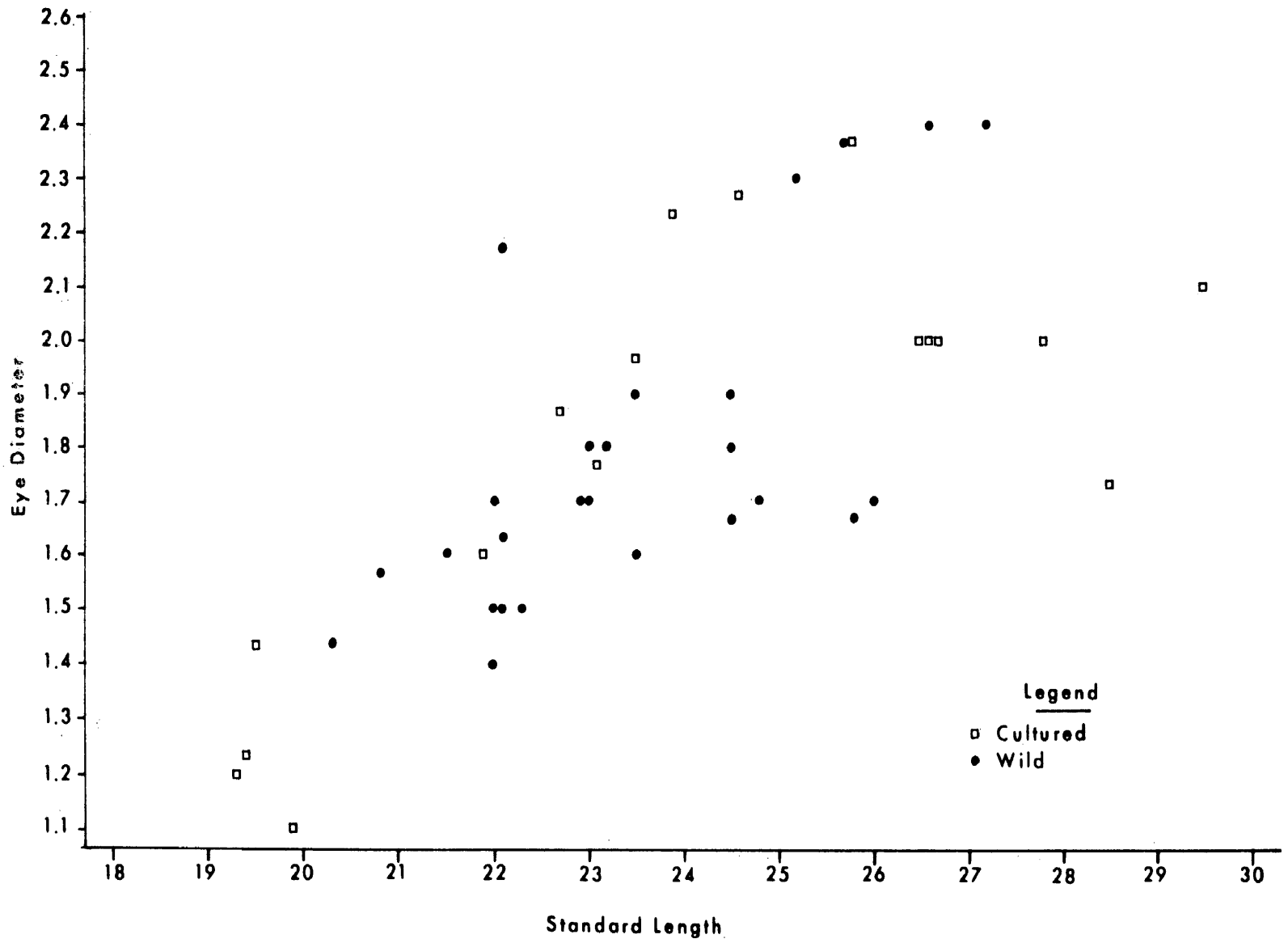
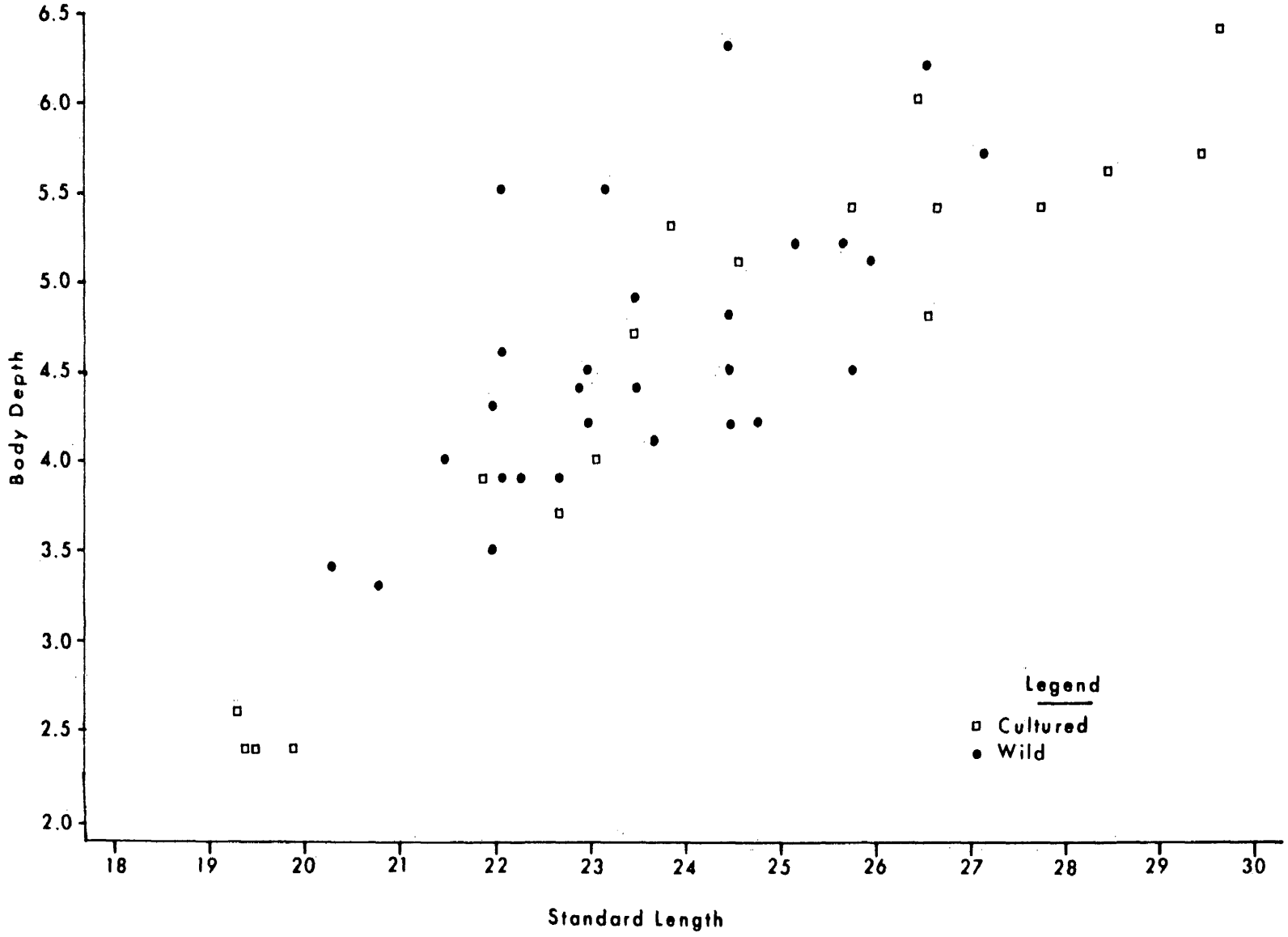

Eye Diameter
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
18
19
20
21
22
23
24
25
26
27
28
29
30
Standard Length
Legend
Cultured
Wild

Figure 25. Scatterplot of body depth (BD) versus standard length (SL) measurements from cultured and wild postflexion Alosa sapidissima (Wilson).


Body Depth
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
18
19
20
21
22
23
24
25
26
27
28
29
30
Standard Length
Legend
Cultured
Wild

APPENDIX 1

List of *Alosa sapidissima* (Wilson) body measurements used to compare cultured (Group 1) versus wild (Group 2) sampled specimens.

AMERICAN SHAD, ALOSA SAPIDISSIMA, LARVAE
CULTURED (GROUP 1) VERSUS WILD (GROUP2)

OBS	GROUP	SL	PAL	PDL	ML	SNTL	MED	AD	LSL	LPAL	LPDL	LML	LSNTL	LMED	LAD
1	1	19.33	13.94	10.44	4.30	1.03	1.20	2.56	1.28623	1.14426	1.01870	0.633468	0.012837	0.079181	0.408240
2	1	19.41	13.31	9.16	4.17	1.08	1.22	2.37	1.28803	1.12418	0.96190	0.620136	0.033424	0.086360	0.374748
3	1	19.47	13.81	9.63	4.25	1.13	1.43	2.41	1.28937	1.14019	0.98363	0.628389	0.053078	0.155336	0.382017
4	1	19.92	13.98	11.21	4.20	0.99	1.11	2.35	1.29929	1.14551	1.04961	0.623249	-0.004365	0.045323	0.371068
5	1	21.90	15.20	10.30	5.10	1.10	1.60	3.90	1.34044	1.18184	1.01284	0.707570	0.041393	0.204120	0.591065
6	1	22.66	15.61	10.56	4.71	1.42	1.86	3.68	1.35526	1.19340	1.02366	0.673021	0.152288	0.269513	0.565848
7	1	23.13	15.00	11.41	5.62	1.33	1.75	4.04	1.36418	1.17609	1.05729	0.749736	0.123852	0.243038	0.606381
8	1	23.46	15.24	10.25	5.73	1.35	1.96	4.68	1.37033	1.18298	1.01072	0.758155	0.130334	0.292256	0.670246
9	1	23.87	14.15	10.13	5.82	1.62	2.23	5.32	1.37785	1.15076	1.00561	0.764923	0.209515	0.348305	0.725912
10	1	24.61	15.65	10.21	5.94	1.32	2.26	5.06	1.39111	1.19451	1.00903	0.773786	0.120578	0.354108	0.704151
11	1	25.76	16.94	11.88	6.76	1.83	2.38	5.39	1.41095	1.22891	1.07482	0.829947	0.262451	0.376577	0.731589
12	1	26.52	16.99	12.58	6.98	1.88	2.00	5.97	1.42357	1.23019	1.09830	0.843159	0.274158	0.301030	0.775978
13	1	26.64	17.47	12.61	6.64	1.72	2.00	6.83	1.42553	1.24229	1.10072	0.822168	0.235528	0.301030	0.883947
14	1	26.67	17.72	12.64	6.71	1.73	1.99	5.36	1.42602	1.24846	1.10175	0.826723	0.238046	0.298853	0.729165
15	1	27.82	18.30	11.93	6.72	1.60	2.00	5.35	1.44436	1.26245	1.07664	0.827369	0.204120	0.301030	0.728354
16	1	28.51	18.83	12.50	6.50	1.50	1.72	5.57	1.45500	1.27485	1.09691	0.812913	0.176091	0.235528	0.745855
17	1	29.50	19.50	11.90	6.65	1.59	2.11	5.70	1.46982	1.29003	1.07555	0.822822	0.201397	0.324282	0.755875
18	1	29.66	19.55	12.93	8.15	1.89	2.64	6.38	1.47217	1.29115	1.11160	0.911158	0.276462	0.421604	0.804821
19	2	19.41	13.31	9.16	4.17	1.08	1.22	2.37	1.28803	1.12418	0.96190	0.620136	0.033424	0.086360	0.374748
20	2	19.47	13.81	9.63	4.25	1.13	1.43	2.41	1.28937	1.14019	0.98363	0.628389	0.053078	0.155336	0.382017
21	2	20.30	13.90	9.50	4.51	0.87	1.43	3.36	1.30750	1.14301	0.97772	0.654177	-0.060481	0.155336	0.526339
22	2	20.80	14.50	9.80	4.70	1.05	1.55	3.33	1.31806	1.16137	0.99123	0.672098	0.021189	0.190332	0.522444
23	2	21.50	15.70	10.20	5.10	1.20	1.60	4.00	1.33244	1.19590	1.00860	0.707570	0.079181	0.204120	0.602060
24	2	21.90	15.20	10.30	5.10	1.10	1.60	3.90	1.34044	1.18184	1.01284	0.707570	0.041393	0.204120	0.591065
25	2	22.00	16.50	10.20	4.90	1.05	1.70	4.30	1.34242	1.21748	1.00860	0.690196	0.021189	0.230449	0.633468
26	2	22.00	15.00	10.55	5.30	1.10	1.50	3.50	1.34242	1.17609	1.02325	0.724276	0.041393	0.176091	0.544068
27	2	22.00	15.50	9.50	4.60	1.20	1.40	3.45	1.34242	1.19033	0.97772	0.662758	0.079181	0.146128	0.537819
28	2	22.09	15.71	9.44	5.59	1.21	2.15	4.58	1.34420	1.19618	0.97497	0.747412	0.082785	0.332438	0.660865
29	2	22.10	15.50	10.60	5.32	1.22	1.62	5.45	1.34439	1.19033	1.02531	0.725912	0.086360	0.209515	0.736397
30	2	22.10	15.20	9.90	5.10	0.90	1.50	3.90	1.34439	1.18184	0.99564	0.707570	-0.045757	0.176091	0.591065
31	2	22.30	15.80	10.10	5.30	1.20	1.50	3.90	1.34830	1.19866	1.00432	0.724276	0.079181	0.176091	0.591065
32	2	22.66	15.61	10.56	4.71	1.42	1.86	3.86	1.35526	1.19340	1.02366	0.673021	0.152288	0.269513	0.586587
33	2	22.86	15.90	10.20	5.70	1.20	1.70	4.40	1.35908	1.20140	1.00860	0.755875	0.079181	0.230449	0.643453
34	2	23.00	15.50	10.20	5.10	1.10	1.80	4.50	1.36173	1.19033	1.00860	0.707570	0.041393	0.255273	0.653213
35	2	23.00	15.00	10.00	5.20	1.10	1.70	4.20	1.36173	1.17609	1.00000	0.716003	0.041393	0.230449	0.623249
36	2	23.00	16.90	10.00	5.20	1.20	1.70	4.20	1.36173	1.22789	1.00000	0.716003	0.079181	0.230449	0.623249
37	2	23.13	15.00	11.41	5.62	1.33	1.75	4.04	1.36418	1.17609	1.05729	0.749736	0.123852	0.243038	0.606381
38	2	23.20	15.80	10.90	5.40	1.31	1.81	5.50	1.36549	1.19866	1.03743	0.732394	0.117271	0.257679	0.740363
39	2	23.50	16.20	10.00	5.10	1.40	1.60	4.90	1.37107	1.20952	1.00000	0.707570	0.146128	0.204120	0.690196
40	2	23.50	18.00	11.40	5.80	1.80	1.90	4.40	1.37107	1.25527	1.05690	0.763428	0.255273	0.278754	0.643453
41	2	23.70	16.50	10.10	5.20	1.31	1.21	4.13	1.37475	1.21748	1.00432	0.716003	0.117271	0.082785	0.615950
42	2	23.87	11.15	10.13	5.82	1.62	2.23	5.32	1.37785	1.04727	1.00561	0.764923	0.209515	0.348305	0.725912
43	2	24.50	16.20	10.90	5.35	1.25	1.65	4.75	1.38917	1.20952	1.03743	0.728354	0.096910	0.217488	0.676694
44	2	24.50	16.50	10.50	5.70	1.35	1.80	4.50	1.38917	1.21748	1.02119	0.755875	0.130334	0.255273	0.653213
45	2	24.50	16.20	10.80	5.40	1.20	1.80	4.20	1.38917	1.20952	1.03302	0.732394	0.079181	0.255273	0.623249
46	2	24.50	16.00	11.20	5.63	1.33	1.90	6.31	1.38917	1.20412	1.04922	0.750508	0.123852	0.278754	0.800029
47	2	24.61	15.72	10.21	5.94	1.32	2.26	5.06	1.39111	1.19645	1.00903	0.773786	0.120578	0.354108	0.704151
48	2	24.80	16.50	11.50	5.90	1.50	1.70	4.20	1.39445	1.21748	1.06070	0.770852	0.176091	0.230449	0.623249
49	2	25.21	17.16	11.86	6.68	1.37	2.30	5.16	1.40157	1.23452	1.07408	0.822168	0.136721	0.361728	0.712650
50	2	25.64	16.51	12.17	6.67	1.86	2.36	5.21	1.40926	1.21775	1.08529	0.824126	0.269513	0.372912	0.716838
51	2	25.76	16.94	11.88	6.76	1.83	2.38	5.39	1.41095	1.22891	1.07482	0.829947	0.262451	0.376577	0.731589
52	2	25.80	16.80	12.00	5.65	1.30	1.65	4.45	1.41162	1.22531	1.07918	0.752048	0.113943	0.217488	0.648360
53	2	26.00	17.00	11.50	5.50	1.30	1.70	5.10	1.41497	1.23045	1.06070	0.740363	0.113943	0.230449	0.707570
54	2	26.58	17.16	11.99	7.01	2.21	2.41	6.16	1.42455	1.23452	1.07882	0.845718	0.344392	0.382017	0.789581
55	2	27.19	17.47	12.11	6.74	2.04	2.40	5.67	1.43441	1.24229	1.08314	0.828660	0.309630	0.380211	0.753583

APPENDIX 2

Univariate comparisons of cultured versus wild sampled *Alosa sapidissima* (Wilson) specimens.

UNIVARIATE STATISTICS FOR CULTURED AND FIELD SAMPLED
AMERICAN SHAD, ALOSA SAPIDISSIMA, POSTFLEXION LARVAE
CULTURED (GROUP=1) AND FIELD (GROUP=2)
GROUP=1

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
SL	18	24.380	3.480	19.330	29.660	0.820	438.840	12.109	14.273
PAL	18	16.177	2.041	13.310	19.550	0.481	291.190	4.167	12.619
PDL	18	11.235	1.176	9.160	12.930	0.277	202.230	1.382	10.465
ML	18	5.828	1.161	4.170	8.150	0.274	104.910	1.349	19.925
SNTL	18	1.451	0.301	0.990	1.890	0.071	26.110	0.091	20.747
HED	18	1.859	0.421	1.110	2.640	0.099	33.460	0.177	22.658
HD	18	4.496	1.333	2.350	6.380	0.314	80.920	1.776	29.646
GROUP=2									
SL	37	23.324	1.875	19.410	27.190	0.308	863.000	3.515	8.038
PAL	37	15.766	1.283	11.150	18.000	0.211	583.350	1.647	8.139
PDL	37	10.605	0.849	9.160	12.170	0.140	392.400	0.721	8.008
ML	37	5.451	0.680	4.170	7.010	0.112	201.680	0.462	12.474
SNTL	37	1.323	0.296	0.870	2.210	0.049	48.960	0.088	22.394
HED	37	1.778	0.328	1.210	2.410	0.054	65.770	0.107	18.438
HD	37	4.434	0.892	2.370	6.310	0.147	164.060	0.795	20.114

CULTURED VERSUS WILD AMERICAN SHAD,
ALOSA SAPIDISSIMA, POSTFLEXION LARVAE.
CULTURED (GROUP=1) AND WILD (GROUP=2)

TTEST PROCEDURE

VARIABLE: SL

GROUP	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > |T|
1	18	24.38000000	3.47979715	0.82019605	19.33000000	29.66000000	UNEQUAL	1.2048	21.9	0.2411
2	37	23.32432432	1.87487857	0.30822814	19.41000000	27.19000000	EQUAL	1.4669	53.0	0.1483

FOR HO: VARIANCES ARE EQUAL, F'= 3.44 WITH 17 AND 36 DF PROB > F'= 0.0018

VARIABLE: PAL

GROUP	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > |T|
1	18	16.17722222	2.04133695	0.48114773	13.31000000	19.55000000	UNEQUAL	0.7823	23.8	0.4418
2	37	15.76621622	1.28325617	0.21096601	11.15000000	18.00000000	EQUAL	0.9128	53.0	0.3656

FOR HO: VARIANCES ARE EQUAL, F'= 2.53 WITH 17 AND 36 DF PROB > F'= 0.0189

VARIABLE: PDL

GROUP	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > |T|
1	18	11.23500000	1.17570630	0.27711663	9.16000000	12.93000000	UNEQUAL	2.0290	25.9	0.0528
2	37	10.60540541	0.84926960	0.13961906	9.16000000	12.17000000	EQUAL	2.2678	53.0	0.0274

FOR HO: VARIANCES ARE EQUAL, F'= 1.92 WITH 17 AND 36 DF PROB > F'= 0.0997

VARIABLE: ML

GROUP	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > |T|
1	18	5.82833333	1.16130378	0.27372193	4.17000000	8.15000000	UNEQUAL	1.2769	22.8	0.2145
2	37	5.45081081	0.67992393	0.11177881	4.17000000	7.01000000	EQUAL	1.5204	53.0	0.1340

FOR HO: VARIANCES ARE EQUAL, F'= 2.92 WITH 17 AND 36 DF PROB > F'= 0.0068

VARIABLE: SNTL

GROUP	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > |T|
1	18	1.45055556	0.30094893	0.07093434	0.99000000	1.89000000	UNEQUAL	1.0795	33.3	0.1888
2	37	1.32324324	0.29632053	0.04871479	0.87000000	2.21000000	EQUAL	1.0876	53.0	0.1828

FOR HO: VARIANCES ARE EQUAL, F'= 1.03 WITH 17 AND 36 DF PROB > F'= 0.9014

CULTURED VERSUS WILD AMERICAN SHAD,
ALOSA SAPIDISSIMA, POSTFLEXION LARVAE.
CULTURED (GROUP=1) AND WILD (GROUP=2)

TTEST PROCEDURE

VARIABLE: MED

GROUP	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > |T|
1	18	1.85888889	0.42118724	0.09927478	1.11000000	2.64000000	UNEQUAL	0.7200	27.4	0.4777
2	37	1.77756757	0.32773978	0.05388009	1.21000000	2.41000000	EQUAL	0.7853	53.0	0.4358

FOR HO: VARIANCES ARE EQUAL, F'= 1.65 WITH 17 AND 36 DF PROB > F'= 0.2026

VARIABLE: RD

GROUP	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > |T|
1	18	4.09555556	1.33276058	0.31413563	2.35000000	6.38000000	UNEQUAL	0.1778	28.7	0.8606
2	37	4.03405405	0.89186901	0.14662236	2.37000000	6.31000000	EQUAL	0.2031	53.0	0.8398

FOR HO: VARIANCES ARE EQUAL, F'= 2.23 WITH 17 AND 36 DF PROB > F'= 0.0422

APPENDIX 3

Analysis of Covariance comparisons for cultured versus wild sampled *Alosa sapidissima* (Wilson) specimens.

ANALYSIS OF COVARIANCE FOR AMERICAN SHAD, ALOSA SAPIDISSIMA.
CULTURED (GROUP 1) VERSUS WILD (GROUP 2) SAMPLED POSTFLEXION LARVAE
MODEL OF PREANAL LENGTH (PAL) VERSUS STANDARD LENGTH (SL)

GENERAL LINEAR MODELS PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
GROUP	2	1 2

NUMBER OF OBSERVATIONS IN DATA SET = 55

ANALYSIS OF COVARIANCE FOR AMERICAN SHAD, ALOSA SAPIDISSIMA.
CULTURED (GROUP 1) VERSUS WILD (GROUP 2) SAMPLED POSTFLEXION LARVAE
MODEL OF PREANAL LENGTH (PAL) VERSUS STANDARD LENGTH (SL)

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PAL

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	90.51011034	30.17003678	36.94	0.0001	0.684809	5.6839
ERROR	51	41.65826057	0.81682864		STD DEV		PAL MEAN
CORRECTED TOTAL	54	132.16837091			0.90378573		15.90072727

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
GROUP	1	2.04553953	2.50	0.1197	1	1.53621387	1.88	0.1763
SL	1	87.02783279	106.54	0.0001	1	76.97389969	94.24	0.0001
SL*GROUP	1	1.43673802	1.76	0.1907	1	1.43673802	1.76	0.1907

ANALYSIS OF COVARIANCE FOR AMERICAN SHAD, ALOSA SAPIDISSIMA.
CULTURED (GROUP 1) VERSUS WILD (GROUP 2) SAMPLED POSTFLEXION LARVAE
MODEL OF PREANAL LENGTH (PAL) VERSUS STANDARD LENGTH (SL)

GENERAL LINEAR MODELS PROCEDURE

LEAST SQUARES MEANS

GROUP	PAL LSMEAN	STD ERR LSMEAN	PROB > |T| HO:LSMEAN=0	PROB > |T| HO: LSMEAN1=LSMEAN2
1	15.7772278	0.2176710	0.0001	0.6079
2	15.9140285	0.1511520	0.0001	

ANALYSIS OF COVARIANCE FOR AMERICAN SHAD, ALOSA SAPIDISSIMA.
CULTURED (GROUP 1) VERSUS WILD (GROUP 2) SAMPLED POSTFLEXION LARVAE
MODEL OF PREDORSAL LENGTH (PDL) VERSUS STANDARD LENGTH (SL)

GENERAL LINEAR MODELS PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
GROUP	2	1 2

NUMBER OF OBSERVATIONS IN DATA SET = 55

ANALYSIS OF COVARIANCE FOR AMERICAN SHAD, ALOSA SAPIDISSIMA,
CULTURED (GROUP 1) VERSUS WILD (GROUP 2) SAMPLED POSTFLEXION LARVAE
MODEL OF PREDORSAL LENGTH (PDL) VERSUS STANDARD LENGTH (SL)

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PDL

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	38.87205217	12.95735072	42.93	0.0001	0.716350	5.0813
ERROR	51	15.39203146	0.30180454		STD DEV		PDL MEAN
CORRECTED TOTAL	54	54.26408364			0.54936740		10.81145455

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
GROUP	1	4.79991472	15.90	0.0002	1	1.07729772	3.57	0.0645
SL	1	33.20035576	110.01	0.0001	1	33.85309920	112.17	0.0001
SL*GROUP	1	0.87178170	2.89	0.0953	1	0.87178170	2.89	0.0953

ANALYSIS OF COVARIANCE FOR AMERICAN SHAD, ALOSA SAPIDISSIMA.
CULTURED (GROUP 1) VERSUS WILD (GROUP 2) SAMPLED POSTFLEXION LARVAE
MODEL OF PREDORSAL LENGTH (PDL) VERSUS STANDARD LENGTH (SL)

GENERAL LINEAR MODELS PROCEDURE

LEAST SQUARES MEANS

GROUP	PDL LSMEAN	STD ERR LSMEAN	PROB > |T| H0:LSMEAN=0	PROB > |T| H0: LSMEAN1=LSMEAN2
1	11.0390705	0.1323116	0.0001	0.0666
2	10.7371619	0.0918780	0.0001	

ANALYSIS OF COVARIANCE FOR AMERICAN SHAD, ALOSA SAPIDISSIMA.
CULTURED (GROUP 1) VERSUS WILD (GROUP 2) SAMPLED POSTFLEXION LARVAE
MODEL OF HEAD LENGTH (HL) VERSUS STANDARD LENGTH (SL)

GENERAL LINEAR MODELS PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
GROUP	2	1 2

NUMBER OF OBSERVATIONS IN DATA SET = 55

ANALYSIS OF COVARIANCE FOR AMERICAN SHAD, ALOSA SAPIDISSIMA,
CULTURED (GROUP 1) VERSUS WILD (GROUP 2) SAMPLED POSTFLEXION LARVAE
MODEL OF HEAD LENGTH (HL) VERSUS STANDARD LENGTH (SL)

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: HL

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	34.49884219	11.49961406	86.29	0.0001	0.835421	6.5487
ERROR	51	6.79631054	0.13326099		STD DEV		HL MEAN
CORRECTED TOTAL	54	41.29515273			0.36504930		5.57436364

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
GROUP	1	1.72582705	12.95	0.0007	1	0.00017716	0.00	0.9711
SL	1	32.77208060	245.92	0.0001	1	30.82549715	231.32	0.0001
SL*GROUP	1	0.00093454	0.01	0.9336	1	0.00093454	0.01	0.9336

ANALYSIS OF COVARIANCE FOR AMERICAN SHAD, ALOSA SAPIDISSIMA,
CULTURED (GROUP 1) VERSUS WILD (GROUP 2) SAMPLED POSTFLEXION LARVAE
MODEL OF HEAD LENGTH (HL) VERSUS STANDARD LENGTH (SL)

GENERAL LINEAR MODELS PROCEDURE

LEAST SQUARES MEANS

GROUP	HL LSMEAN	STD ERR LSMEAN	PROB > |T| H0:LSMEAN=0	PROB > |T| H0: LSMEAN1=LSMEAN2
1	5.60440641	0.08791979	0.0001	0.6702
2	5.55855516	0.06105201	0.0001	

ANALYSIS OF COVARIANCE FOR AMERICAN SHAD, ALOSA SAPIDISSIMA,
CULTURED (GROUP 1) VERSUS WILD (GROUP 2) SAMPLED POSTFLEXION LARVAE
MODEL OF SNOUT LENGTH (SNTL) VERSUS STANDARD LENGTH (SL)

GENERAL LINEAR MODELS PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
GROUP	2	1 2

NUMBER OF OBSERVATIONS IN DATA SET = 55

ANALYSIS OF COVARIANCE FOR AMERICAN SHAD, ALOSA SAPIDISSIMA.
CULTURED (GROUP 1) VERSUS WILD (GROUP 2) SAMPLED POSTFLEXION LARVAE
MODEL OF SNOUT LENGTH (SNTL) VERSUS STANDARD LENGTH (SL)

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SNTL

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	2.99628257	0.99876086	26.80	0.0001	0.611864	14.1438
ERROR	51	1.90069197	0.03726847		STD DEV		SNTL MEAN
CORRECTED TOTAL	54	4.89697455			0.19305043		1.36490909

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
GROUP	1	0.19626929	5.27	0.0259	1	0.14866074	3.99	0.0511
SL	1	2.65894421	71.35	0.0001	1	2.79942256	75.12	0.0001
SL*GROUP	1	0.14106907	3.79	0.0572	1	0.14106907	3.79	0.0572

ANALYSIS OF COVARIANCE FOR AMERICAN SHAD, ALOSA SAPIDISSIMA,
CULTURED (GROUP 1) VERSUS WILD (GROUP 2) SAMPLED POSTFLEXION LARVAE
MODEL OF SNOUT LENGTH (SNTL) VERSUS STANDARD LENGTH (SL)

GENERAL LINEAR MODELS PROCEDURE

LEAST SQUARES MEANS

GROUP	SNTL LSMEAN	STD ERR LSMEAN	PROB > |T| H0:LSMEAN=0	PROB > |T| H0: LSMEAN1=LSMEAN2
1	1.39850892	0.04649496	0.0001	0.5358
2	1.36322151	0.03228637	0.0001	

ANALYSIS OF COVARIANCE FOR AMERICAN SHAD, ALOSA SAPIDISSIMA,
CULTURED (GROUP 1) VERSUS WILD (GROUP 2) SAMPLED POSTFLEXION LARVAE
MODEL OF EYE DIAMETER (HED) VERSUS STANDARD LENGTH (SL)

GENERAL LINEAR MODELS PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
GROUP	2	1 2

NUMBER OF OBSERVATIONS IN DATA SET = 55

ANALYSIS OF COVARIANCE FOR AMERICAN SHAD, ALOSA SAPIDISSIMA,
CULTURED (GROUP 1) VERSUS WILD (GROUP 2) SAMPLED POSTFLEXION LARVAE
MODEL OF EYE DIAMETER (HED) VERSUS STANDARD LENGTH (SL)

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: HED

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	3.80295487	1.26765162	20.46	0.0001	0.546187	13.7963
ERROR	51	3.15978332	0.06195654		STD DEV		HED MEAN
CORRECTED TOTAL	54	6.96273818			0.24891070		1.80418182

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
GROUP	1	0.08007932	1.29	0.2609	1	0.05158325	0.83	0.3658
SL	1	3.66551781	59.16	0.0001	1	3.67260403	59.28	0.0001
SL*GROUP	1	0.05735773	0.93	0.3405	1	0.05735773	0.93	0.3405

ANALYSIS OF COVARIANCE FOR AMERICAN SHAD, ALOSA SAPIDISSIMA.
CULTURED (GROUP 1) VERSUS WILD (GROUP 2) SAMPLED POSTFLEXION LARVAE
MODEL OF EYE DIAMETER (HED) VERSUS STANDARD LENGTH (SL)

GENERAL LINEAR MODELS PROCEDURE

LEAST SQUARES MEANS

GROUP	HED LSMEAN	STD ERR LSMEAN	PROB > |T| H0:LSMEAN=0	PROB > |T| H0: LSMEAN1=LSMEAN2
1	1.79162591	0.05994855	0.0001	0.7027
2	1.81963691	0.04162862	0.0001	

ANALYSIS OF COVARIANCE FOR AMERICAN SHAD, ALOSA SAPIDISSIMA,
CULTURED (GROUP 1) VERSUS WILD (GROUP 2) SAMPLED POSTFLEXION LARVAE
MODEL OF BODY DEPTH (BD) VERSUS STANDARD LENGTH (SL)

GENERAL LINEAR MODELS PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
GROUP	2	1 2

NUMBER OF OBSERVATIONS IN DATA SET = 55

ANALYSIS OF COVARIANCE FOR AMERICAN SHAD, ALOSA SAPIDISSIMA.
CULTURED (GROUP 1) VERSUS WILD (GROUP 2) SAMPLED POSTFLEXION LARVAE
MODEL OF BODY DEPTH (BD) VERSUS STANDARD LENGTH (SL)

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: BD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	44.26084517	14.75361506	51.48	0.0001	0.751742	12.0192
ERROR	51	14.61689301	0.28660575		STD DEV		BD MEAN
CORRECTED TOTAL	54	58.87773818			0.53535572		4.45418182

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
GROUP	1	0.04580185	0.16	0.6910	1	0.00070258	0.00	0.9607
SL	1	44.19333425	154.20	0.0001	1	42.13277116	147.01	0.0001
SL*GROUP	1	0.02170907	0.08	0.7843	1	0.02170907	0.08	0.7843

ANALYSIS OF COVARIANCE FOR AMERICAN SHAD, ALOSA SAPIDISSIMA.
CULTURED (GROUP 1) VERSUS WILD (GROUP 2) SAMPLED POSTFLEXION LARVAE
MODEL OF BODY DEPTH (BD) VERSUS STANDARD LENGTH (SL)

GENERAL LINEAR MODELS PROCEDURE

LEAST SQUARES MEANS

GROUP	BD LSMEAN	STD ERR LSMEAN	PROB > |T| H0:LSMEAN=0	PROB > |T| H0: LSMEAN1=LSMEAN2
1	4.24110417	0.12893701	0.0001	0.0451
2	4.56359148	0.08953460	0.0001	

APPENDIX 4

Multivariate Analysis of Variance for cultured versus wild sampled *Alosa sapidissima* (Wilson) specimens.

MULTIVARIATE ANALYSIS OF VARIANCE FOR COMPARISON
OF WILD AND CULTURED (GROUPS=TRTS) POSTFLEXION
MORPHOMETRIC VARIABLES (VARIABLES=BLKS) FOR AMERICAN SHAD
ALOSA SAPIDISSIMA (WILSON)

GENERAL LINEAR MODELS PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
GROUP	2	1 2

NUMBER OF OBSERVATIONS IN DATA SET = 55

MULTIVARIATE ANALYSIS OF VARIANCE FOR COMPARISON
OF WILD AND CULTURED (GROUPS=TRTS) POSTFLEXION
MORPHOMETRIC VARIABLES (VARIABLES=BLKS) FOR AMERICAN SHAD
ALOSA SAPIDISSIMA (WILSON)

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SL

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	13.49499007	13.49499007	2.15	0.1483	0.039015	10.5803
ERROR	53	332.39890811	6.27167751		STD DEV		SL MEAN
CORRECTED TOTAL	54	345.89389818			2.50433175		23.66981818

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
GROUP	1	13.49499007	2.15	0.1483	1	13.49499007	2.15	0.1483

MULTIVARIATE ANALYSIS OF VARIANCE FOR COMPARISON
OF WILD AND CULTURED (GROUPS=TRTS) POSTFLEXION
MORPHOMETRIC VARIABLES (VARIABLES=BLKS) FOR AMERICAN SHAD
ALOSA SAPIDISSIMA (WILSON)

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PAL

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	2.04553953	2.04553953	0.83	0.3655	0.015477	9.8542
ERROR	53	130.12283138	2.45514776		STD DEV		PAL MEAN
CORRECTED TOTAL	54	132.16837091			1.56689111		15.90072727

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
GROUP	1	2.04553953	0.83	0.3655	1	2.04553953	0.83	0.3655

MULTIVARIATE ANALYSIS OF VARIANCE FOR COMPARISON
OF WILD AND CULTURED (GROUPS=TRTS) POSTFLEXION
MORPHOMETRIC VARIABLES (VARIABLES=BLKS) FOR AMERICAN SHAD
ALOSA SAPIDISSIMA (WILSON)

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PDL

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	4.79991472	4.79991472	5.14	0.0274	0.088455	8.9356
ERROR	53	49.46416892	0.93328621		STD DEV		PDL MEAN
CORRECTED TOTAL	54	54.26408364			0.96606739		10.81145455

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
GROUP	1	4.79991472	5.14	0.0274	1	4.79991472	5.14	0.0274

MULTIVARIATE ANALYSIS OF VARIANCE FOR COMPARISON
OF WILD AND CULTURED (GROUPS=TRTS) POSTFLEXION
MORPHOMETRIC VARIABLES (VARIABLES=BLKS) FOR AMERICAN SHAD
ALOSA SAPIDISSIMA (WILSON)

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: HL

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	1.72582705	1.72582705	2.31	0.1344	0.041792	15.5005
ERROR	53	39.56932568	0.74659105		STD DEV		HL MEAN
CORRECTED TOTAL	54	41.29515273			0.86405500		5.57436364

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
GROUP	1	1.72582705	2.31	0.1344	1	1.72582705	2.31	0.1344

MULTIVARIATE ANALYSIS OF VARIANCE FOR COMPARISON
OF WILD AND CULTURED (GROUPS=TRTS) POSTFLEXION
MORPHOMETRIC VARIABLES (VARIABLES=BLKS) FOR AMERICAN SHAD
ALOSA SAPIDISSIMA (WILSON)

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SNTL

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	0.19626929	0.19626929	2.21	0.1428	0.040080	21.8193
ERROR	53	4.70070526	0.08869255		STD DEV		SNTL MEAN
CORRECTED TOTAL	54	4.89697455			0.29781295		1.36490909

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
GROUP	1	0.19626929	2.21	0.1428	1	0.19626929	2.21	0.1428

MULTIVARIATE ANALYSIS OF VARIANCE FOR COMPARISON
OF WILD AND CULTURED (GROUPS=TRTS) POSTFLEXION
MORPHOMETRIC VARIABLES (VARIABLES=BLKS) FOR AMERICAN SHAD
ALOSA SAPIDISSIMA (WILSON)

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: HED

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	0.08007932	0.08007932	0.62	0.4358	0.011501	19.9738
ERROR	53	6.88265886	0.12986149		STD DEV		HED MEAN
CORRECTED TOTAL	54	6.96273818			0.36036299		1.80418182

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
GROUP	1	0.08007932	0.62	0.4358	1	0.08007932	0.62	0.4358

MULTIVARIATE ANALYSIS OF VARIANCE FOR COMPARISON
OF WILD AND CULTURED (GROUPS=TRTS) POSTFLEXION
MORPHOMETRIC VARIABLES (VARIABLES=BLKS) FOR AMERICAN SHAD
ALOSA SAPIDISSIMA (WILSON)

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: BD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	0.04580185	0.04580185	0.04	0.8398	0.000778	23.6538
ERROR	53	58.83193634	1.11003653		STD DEV		BD MEAN
CORRECTED TOTAL	54	58.87773818			1.05358271		4.45418182

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
GROUP	1	0.04580185	0.04	0.8398	1	0.04580185	0.04	0.8398

MULTIVARIATE ANALYSIS OF VARIANCE FOR COMPARISON
OF WILD AND CULTURED (GROUPS=TRTS) POSTFLEXION
MORPHOMETRIC VARIABLES (VARIABLES=BLKS) FOR AMERICAN SHAD
ALOSA SAPIDISSIMA (WILSON)

GENERAL LINEAR MODELS PROCEDURE

E = ERROR SS&CP MATRIX

DF=53	SL	PAL	PDL	HL	SNTL	HED	BD
SL	332.39890811	170.08220541	105.05123514	104.37147027	29.72928108	34.90578919	121.20155135
PAL	170.08220541	130.12283138	58.82500676	51.93203018	13.78358183	14.26820390	56.34644535
PDL	105.05123514	58.82500676	49.46416892	35.90778784	11.16430135	10.42858649	36.49488919
HL	104.37147027	51.93203018	35.90778784	39.56932568	11.26021937	13.97943964	42.09504505
SNTL	29.72928108	13.78358183	11.16430135	11.26021937	4.70070526	4.43750300	12.06365796
HED	34.90578919	14.26820390	10.42858649	13.97943964	4.43750300	6.88265886	16.19667598
BD	121.20155135	56.34644535	36.49488919	42.09504505	12.06365796	16.19667598	58.83193634

PARTIAL CORRELATION COEFFICIENTS FROM THE ERROR SS&CP MATRIX / PROB > |R|

DF=52	SL	PAL	PDL	HL	SNTL	HED	BD
SL	1.000000	0.817810	0.819268	0.910066	0.752096	0.729776	0.866706
	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
PAL	0.817810	1.000000	0.733229	0.723734	0.557319	0.476776	0.643996
	0.0001	0.0000	0.0001	0.0001	0.0001	0.0003	0.0001
PDL	0.819268	0.733229	1.000000	0.811641	0.732158	0.565200	0.676519
	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001
HL	0.910066	0.723734	0.811641	1.000000	0.825631	0.847095	0.872459
	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001
SNTL	0.752096	0.557319	0.732158	0.825631	1.000000	0.780152	0.725422
	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001
HED	0.729776	0.476776	0.565200	0.847095	0.780152	1.000000	0.804899
	0.0001	0.0003	0.0001	0.0001	0.0001	0.0000	0.0001
BD	0.866706	0.643996	0.676519	0.872459	0.725422	0.804899	1.000000
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000

MULTIVARIATE ANALYSIS OF VARIANCE FOR COMPARISON
OF WILD AND CULTURED (GROUPS=TRTS) POSTFLEXION
MORPHOMETRIC VARIABLES (VARIABLES=BLKS) FOR AMERICAN SHAD
ALOSA SAPIDISSIMA (WILSON)

GENERAL LINEAR MODELS PROCEDURE

H = TYPE IV SSRCP MATRIX FOR: GROUP

DF=1	SL	PAL	PDL	HL	SNTL	HED	BD
SL	13.49499007	5.25400187	8.04827941	4.82597337	1.62746801	1.03955263	0.78619047
PAL	5.25400187	2.04553953	3.13343506	1.87889527	0.63362180	0.40472882	0.30608738
PDL	8.04827941	3.13343506	4.79991472	2.87816307	0.97060592	0.61997897	0.46887627
HL	4.82597337	1.87889527	2.87816307	1.72582705	0.58200245	0.37175672	0.28115132
SNTL	1.62746801	0.63362180	0.97060592	0.58200245	0.19626929	0.12536791	0.09481295
HED	1.03955263	0.40472882	0.61997897	0.37175672	0.12536791	0.08007932	0.06056221
BD	0.78619047	0.30608738	0.46887627	0.28115132	0.09481295	0.06056221	0.04580185

CHARACTERISTIC ROOTS AND VECTORS OF: E INVERSE * H, WHERE H = TYPE IV SSRCP MATRIX FOR: GROUP E = ERROR SSRCP MATRIX

CHARACTERISTIC ROOT	PERCENT	CHARACTERISTIC VECTOR V'EV=1						
		SL	PAL	PDL	HL	SNTL	HED	BD
0.22202381	100.00	0.05753109	-0.05769518	0.11087689	0.10797055	-0.00210301	0.00709025	-0.20309850
0.00000000	0.00	-0.01616281	0.03051633	0.15750154	-0.32934724	-0.30681243	0.84547543	0.00000000
0.00000000	0.00	0.08249158	0.01763507	-0.14983050	0.00000000	0.00000000	0.00000000	0.00000000
0.00000000	0.00	-0.07131217	0.14579495	0.01536463	0.01849737	0.00362116	0.00104605	-0.02996386
0.00000000	0.00	-0.11021542	0.01985724	-0.07345136	0.41045635	0.00145672	0.00042081	-0.01205385
0.00000000	0.00	-0.00359189	0.02677909	-0.06056450	-0.20314107	0.84816288	0.00022297	-0.00638678
0.00000000	0.00	-0.06968313	-0.00931839	0.14182180	-0.03138642	0.07635478	-0.29594167	0.23246593

MULTIVARIATE ANALYSIS OF VARIANCE FOR COMPARISON
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MORPHOMETRIC VARIABLES (VARIABLES=BLKS) FOR AMERICAN SHAD
ALOSA SAPIDISSIMA (WILSON)

GENERAL LINEAR MODELS PROCEDURE

MANOVA TEST CRITERIA FOR THE HYPOTHESIS OF NO OVERALL GROUP EFFECT

H = TYPE IV SS&CP MATRIX FOR: GROUP
E = ERROR SS&CP MATRIX
P = DEP. VARIABLES = 7
Q = HYPOTHESIS DF = 1
NE= DF OF E = 53
S = MIN(P,Q) = 1
M = .5(ABS(P-Q)-1) = 2.5
N = .5(NE-P-1) = 22.5

HOTELLING-LAWLEY TRACE = TR(E**-1*H) = 0.22202381 (SEE PILLAI'S TABLE #3)

F APPROXIMATION = 2(S*N+1)*TR(E**-1*H)/(S*S*(2M+S+1)) WITH S(2M+S+1) AND 2(S*N+1) DF

F(7,47) = 1.49 PROB > F = 0.1938

PILLAI'S TRACE V = TR(H*INV(H+E)) = 0.18168534 (SEE PILLAI'S TABLE #2)

F APPROXIMATION = (2N+S+1)/(2M+S+1) * V/(S-V) WITH S(2M+S+1) AND S(2N+S+1) DF

F(7,47) = 1.49 PROB > F = 0.1938

WILKS' CRITERION L = DET(E)/DET(H+E) = 0.81831466 (SEE RAO 1973 P 555)

EXACT F = (1-L)/L*(NE+Q-P)/P WITH P AND NE+Q-P DF

F(7,47) = 1.49 PROB > F = 0.1938

ROY'S MAXIMUM ROOT CRITERION = 0.22202381 (SEE AMS VOL 31 P 625)

FIRST CANONICAL VARIABLE YIELDS AN F UPPER BOUND

F(7,53) = 11.77 (UPPER BOUND)

APPENDIX 5

Yolksac *Alosa sapidissima* (Wilson) body morphology and proportion measurements.

Morphometrics in mm yolksac larvae American shad, Alosa sapidissima (Wilson)

SI	N	STAT	TL	SL	PAL	PDL	HL	HED	YD
6.50 to 6.99	4	$\bar{x}$	6.75	6.42	5.46	1.21	.70	.34	1.54
		SD	.20	.16	.12	.05	.04	.05	.37
		R	6.50 - 6.98	6.22 - 6.60	5.30 - 5.58	1.15 - 1.25	.65 - .75	.30 - .40	1.10 - 2.00
7.00 to 7.49	4	$\bar{x}$	7.24	6.85	5.74	*1.22	.67	.36	2.03
		SD	.18	.21	.31	.05	.04	.03	.15
		R	7.05 - 7.49	6.57 - 7.05	5.35 - 6.10	1.19 - 1.28	.61 - .70	.33 - .39	1.85 - 2.20
7.50 to 7.99	23	$\bar{x}$	7.72	7.39	6.15	*1.34	.79	.38	1.71
		SD	.11	.13	.12	.12	.08	.03	.33
		R	7.50 - 7.90	7.05 - 7.55	5.90 - 6.40	1.15 - 1.60	.63 - .91	.31 - .41	1.10 - 2.05
8.00 to 8.49	42	$\bar{x}$	8.24	7.94	6.60	1.46	.86	*.38	1.58
		SD	.14	.14	.13	.14	.08	.02	.31
		R	8.00 - 8.49	7.70 - 8.20	6.38 - 6.97	1.23 - 1.70	.70 - .94	.34 - .42	1.00 - 2.05
8.50 to 8.99	14	$\bar{x}$	8.65	8.35	6.93	*1.62	.89	.37	1.38
		SD	.16	.15	.19	.46	.10	.03	.32
		R	8.50 - 8.93	8.10 - 8.58	6.53 - 7.15	1.42 - 3.10	.65 - .96	.32 - .41	.98 - 1.95
9.00 to 9.49	5	$\bar{x}$	9.11	8.82	7.27	2.28	.95	.36	1.16
		SD	.09	.11	.11	.86	.05	.05	.38
		R	9.03 - 9.25	8.70 - 9.00	7.13 - 7.40	1.55 - 3.60	.90 - 1.01	.31 - .43	.70 - 1.70
9.50 to 9.99	3	$\bar{x}$	9.69	9.36	7.59	.437	1.17	.46	.79
		SD	.16	.34	.17	1.92	.16	.08	.25
		R	9.53 - 9.85	8.99 - 9.65	7.46 - 7.78	2.80 - 6.60	1.05 - 1.35	.37 - .50	.55 - 1.05
10.00 to 10.60	2	$\bar{x}$	10.30	10.15	8.00	4.73	1.28	.47	1.03
		SD	.42	.71	.07	2.64	.11	.04	.46
		R	10.00 - 10.60	9.65 - 10.28	7.95 - 8.05	2.87 - 6.60	1.20 - 1.35	.45 - .48	.70 - 1.35
Totals/Means	97		8.46	8.16	6.72	2.27	0.91	0.39	1.40

$\bar{x}$ = Mean; SD = Standard Deviation; R = Range; * = missing values = 1; TL = Total Length; SL = Notochord Length; PAL = Preanal Length; PDL = Predorsal Length; HL = Head Length; HED = Horizontal Eye Diameter; YD = Yolk Diameter

Morphometric ratios for yolksac larvae American shad, Alosa sapidissima (Wilson): Based on Notochord Length

SI	N	STAT	PAL/SL	PDL/SL	HL/SL	YD/SL
6.50 to 6.99	4	$\bar{x}$	.852	.189	.109	.224
		SD	.025	.004	.006	.081
		R	.826 - .876	.185 - .194	.101 - .114	.177 - .312
7.00 to 7.49	4	$\bar{x}$	.837	*.176	.098	.296
		SD	.021	.009	.004	.024
		R	.814 - .865	.169 - .187	.093 - .102	.270 - .320
7.50 to 7.99	23	$\bar{x}$	.832	*.182	.107	.231
		SD	.019	.017	.010	.046
		R	.781 - .858	.160 - .213	.086 - .126	.147 - .298
8.00 to 8.49	42	$\bar{x}$	.831	.183	.109	*.199
		SD	.014	.017	.011	.039
		R	.804 - .882	.153 - .214	.087 - .121	.128 - .265
8.50 to 8.99	14	$\bar{x}$	8.30	*.195	1.06	.165
		SD	.017	.056	.011	.040
		R	.806 - .851	.167 - .376	.085 - .116	.114 - .229
9.00 to 9.49	5	$\bar{x}$	.823	.259	.108	.131
		SD	.010	.100	.007	.041
		R	.809 - .835	.172 - .305	.100 - .116	.080 - .189
9.50 to 9.99	3	$\bar{x}$	.811	.465	.124	.085
		SD	.019	.193	.014	.027
		R	.794 - .832	.296 - .675	.116 - .140	.057 - .111
10.00 to 10.49	2	$\bar{x}$	.804	.481	.129	.102
		SD	.029	.286	.016	.041
		R	.783 - .824	2.79 - .684	.117 - .140	.073 - .131

$\bar{x}$ = Mean; SD = Standard Deviation; * = missing values = 1; SI = Size Interval; N = Number of Specimens; STAT = Statistic; PAL = Preanal Length; PDL = Predorsal Length; HL = Head Length; YD = Yolk Diameter; SL = Notochord Length

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